METAL PROGRESS

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CURRENT SHORTAGES

in nickel and other metals

By Ernest E. Thum
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SINCE THE ARTICLE ON STRATEGIC AND critical metals was published last month, containing an all-too brief paragraph on nickel saying that there should be a comfortable surplus of this essential metal, several metallurgists connected with the alloy steel industry have asked the Editor where they can find some more of it, their present supplies being strictly hand-to-mouth.

Evidently a similar situation is developing in other metals. Aluminum is already "rationed", according to the daily press. Zinc is being closely watched by a committee of producers. Stringency in spot tungsten has been eased somewhat by the Government's stock-pile.

Steel, for which we have enormous capacity, appears frequently in the public prints and radio discussions, one side basing an argument for large plant expansions on present 90% + operations, long forward deliveries quoted on new orders, unpredictable but certainly large future demands for national defense, and the Administration's evident desire for "business as usual" or more so. Advocates of the idea that we now have ample steel making capacity rest their case on a desire to avoid a large number of idle plants after the present emergency; likewise an examination of the trends of consumption and capacity to fabricate steel in the important industries (such as automotive, container, construction) indicates that the United States *can't* absorb much more than 53,000,000 tons of steel ingots a year in civilian needs, shipbuilding and transportation, leaving 21,000,000 available for defense out of our present 84,000,000 tons capacity.

Whether 21,000,000 tons of steel ingots will be enough for munitions depends on the defense program and its associated requirements, and this is now only nebulously understood. However, some inkling may be had from statistics about the German steel industry. In 1939 it produced about 27 million tons of ingots in plants in Germany, Austria, Czecho-Slovakia and Poland. This is highest on record by about 6%, and some deductions must be made for domestic consumption and export to its satellites. The remainder for munitions and war effort then comes down to a figure on the same order as the current consumption rate of steel in England (production plus imports) quoted in the article last month at 22,000,000 tons of ingots. This, by the way, includes 7,000,000 tons imported from America, and would leave us that much less.

Whatever the outcome of the argument about sufficiency of our present steel making capacity may be, the Office of Production Management in Washington has already issued letters of advice which foreshadow a more careful allocation of the available steel. Obviously, strict priorities should be imposed only if the emergency can be met in no other way, because restriction of the free circulation of raw materials and semi-finished articles is as necessary to a healthy industrial economy as the life blood is to an individual. A small interruption may cause unsuspected dislocations.

Take a single instance from magnesium. Magnesium should be easy to handle as a strategic metal, for the American supply comes from a single producer, the amount going to

each customer and its approximate use can be estimated accurately, the metal is so new that the uses are not yet legion, the largest intended use is for aircraft and engine parts (and our aircraft program is more nearly established than any other branch of our effort, save only the naval program). So we ought to be able to move in the magnesium industry with a fair degree of assurance. However, a recent note to the principal producer from the Office of Production Management was interpreted to mean that no more magnesium should be delivered to lead refineries, where it is used to remove traces of bismuth to the point acceptable to manufacturers of battery plates and lead-sheathed cable. Now, either the Office of Production Management must change its ruling, or the battery and cable people must reassess the influence of a little bismuth in their lead, or the lead refineries must scramble for a dribble of scrap and secondary magnesium, or metallurgists find another commercial process for taking bismuth out of lead, a process that so far has escaped years of careful search.

But to get back to nickel. As is well known, Canada produces more than 85% of the world's supply of metal. The International Nickel Co. has, by wise investigation, promotion and development, continually increased the industrial uses of nickel and its producing plant (mines, smelters, refineries, fabricating divisions). Total world production in 1937 and again in 1939, and doubtless again in 1940, was at an all-time high, representing the culmination of successful researches and new applications, the rapidly expanding production of armaments and a hoarding of reserve stocks. Look at the record*:

Year:	1929	63,000	tons nickel
	1933	50,000	produced
	1935	82,000	
	1936	98,000	
	1937	126,000	
	1938	122,000	
	1939	130,000	

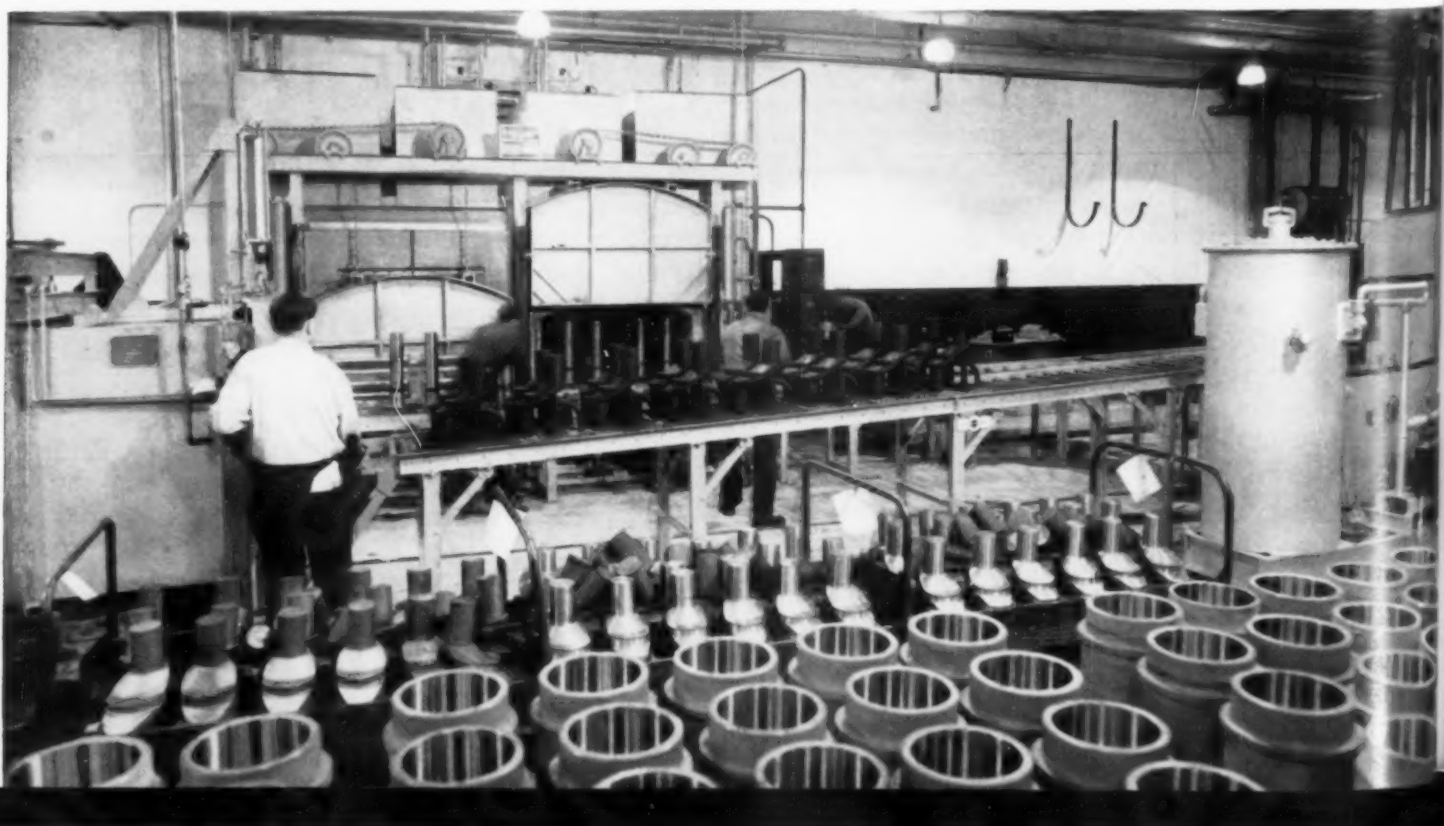
Figures are lacking as to where this nickel eventually is consumed, but it is known that at least half of it is used for alloying iron and steel and that the ups and downs in the nickel and steel industries are fairly parallel. Also it is known that over the last 25 years, the United States has used about 40% of the world's nickel production, and this ratio is close enough to our relative steel capacity that the amount of nickel required in other countries (and the amount that is being diverted from countries under Axis control) can be estimated from the following figures, as of 1939:

United States	36%	of world's steel
British Empire	13%	production
Germany and Italy	20%	
Japan	5%	
Russia	13%	
France, Belgium, Luxemburg	10%	

Such a table as this is the basis of last month's statement, "Since none of the Continental powers are able to draw upon the Cana-

*From an article by M. Tremblay, Ontario Department of Mines, in "The Mineral Industry During 1939".

Aircraft Engine Parts Require Alloy Steel and, Due to Rigid Mill Inspection and Large Amount of Machining, a Disproportionate Amount Goes Into Scrap and Turnings. This view is in the heat treating department of Wright Aeronautical Corp., Paterson, N. J., and shows cylinders ready for nitriding in foreground, crankshaft center sections behind (and on conveyor in middle distance enroute from quench to drawing furnace at extreme left), and propeller shafts at rear being loaded into oven furnace



than supply for their customary amounts, a comfortable surplus for the British and American metallurgical industry should always be available." As a matter of fact, the Editor is informed that a computation made recently indicated that the total of British and U. S. defense nickel requirements (that is, the munitions steel to be made in the United States in 1941) plus American civil needs (placed at about 41,000 tons, the record amount used in 1937) gave a figure that was less than the probable rate of deliveries to the U. S. market during 1941 of the principal Canadian producer, to say nothing of the nickel from the Falconbridge mine in Canada formerly refined in Norway, and the nickel recovered in the U. S. as a byproduct from electrolytic copper refineries.

Yet American consumers are undoubtedly short of nickel right now! The Canadian mines are producing at capacity, and are shipping all they make. Owing to the control exercised by the Canadian Government, first attention is given to British and Canadian orders. From the surplus, current shipments are being allocated to customers in the United States and Canada in accordance with previous experience; unusually large orders, or orders of any size from new customers, are supplied only on receiving assurance as to the defense nature and necessity of the product for which the metal is intended. There is little chance for a quick gain in output; the leading producer's equipment is well balanced so there is no bottleneck in mine, smelter or refinery. Any expansion program would involve all departments and would be a major operation requiring years rather than months.

Some speculation as to the cause of the present squeeze is warranted. The "normal" requirements of the American metallurgical industry may be figured by adding the total steel ingot production for 1930-39, and our total nickel consumption. It comes to 1.6 lb. of nickel per ton of steel — a convenient figure which does not mean that *all* nickel is consumed by the steel industry, but assumes that other branches of industry rise and fall in activity (and nickel consumption) more or less in step with the steel industry. Since we produced 66¾ million tons of steel in 1940, it might therefore be expected that we would absorb 66¾ million × 1.6, or 118 million lb. of nickel (59,000 tons), whereas we actually imported 141 million lb. of pig, ingot and shot metal and another 35 million lb. of nickel in matte. This indicates use of about 2.6 lb. nickel per ton of steel.

What are the reasons for this present 60% increase over "normal" nickel consumption?

First is the sudden increase in arms and armor production, and these require a disproportionately high amount of nickel steel. Furthermore, the nickel is on the "high side" — specifications frequently call for 3½ and 5% nickel steels whereas industrial uses now favor the ones carrying 1% to 2%. In short, we are making much more nickel steel and it contains unusually high amounts of nickel.

Next is the human desire of all factors in industry, from steel producer down to gear manufacturer and automobile user, to increase his inventories — to buy while he can get what he thinks he will need before the price goes up. This means that users of all sorts of nickel alloys — electroplaters, foundries, fabricating shops in monel and stainless, users of electrical resistance alloys and heat resisting alloys — are laying metal and parts away against a future shortage. Crass hoarding probably is rare, yet in the aggregate this increase in inventory is an important factor in the tight situation.

Both of these items require a rapid increase in rate of alloy steel and metal production, and this in turn is responsible for an even larger poundage of nickel locked up "in process". In steady operation, the amount of material in process and the scrap and waste production bears a fairly constant relation to the output. For instance, 1 ton of nickel would make about 12 tons of 18-8 stainless steel ingot, but due to high losses in making and fabricating sheet metal articles this eventually would be enough for only about 4 tons of welded exhaust manifolds for aircraft engines. In this case 1350 of the 2000 lb. of nickel originally furnished the steel mill has been scrapped enroute, as croppings, scale, trimmings, rejects, and welding shop scrap. Of course, much of this can be eventually recovered, but the illustration merely shows how it takes a disproportionately large amount of alloy to expand quickly the output of finished articles of alloy steel.

Whether one confidently expects the nickel situation will ease before long will depend on his point of view. Inventories cannot be indefinitely expanded; the circulating load of metal in process should reach equilibrium sooner or later. On the other hand, we do not yet realize that an "all-out" program of preparedness utterly transcends any prediction based on peace-time industry. An all-devouring maw, it takes all you have, and then asks for more.

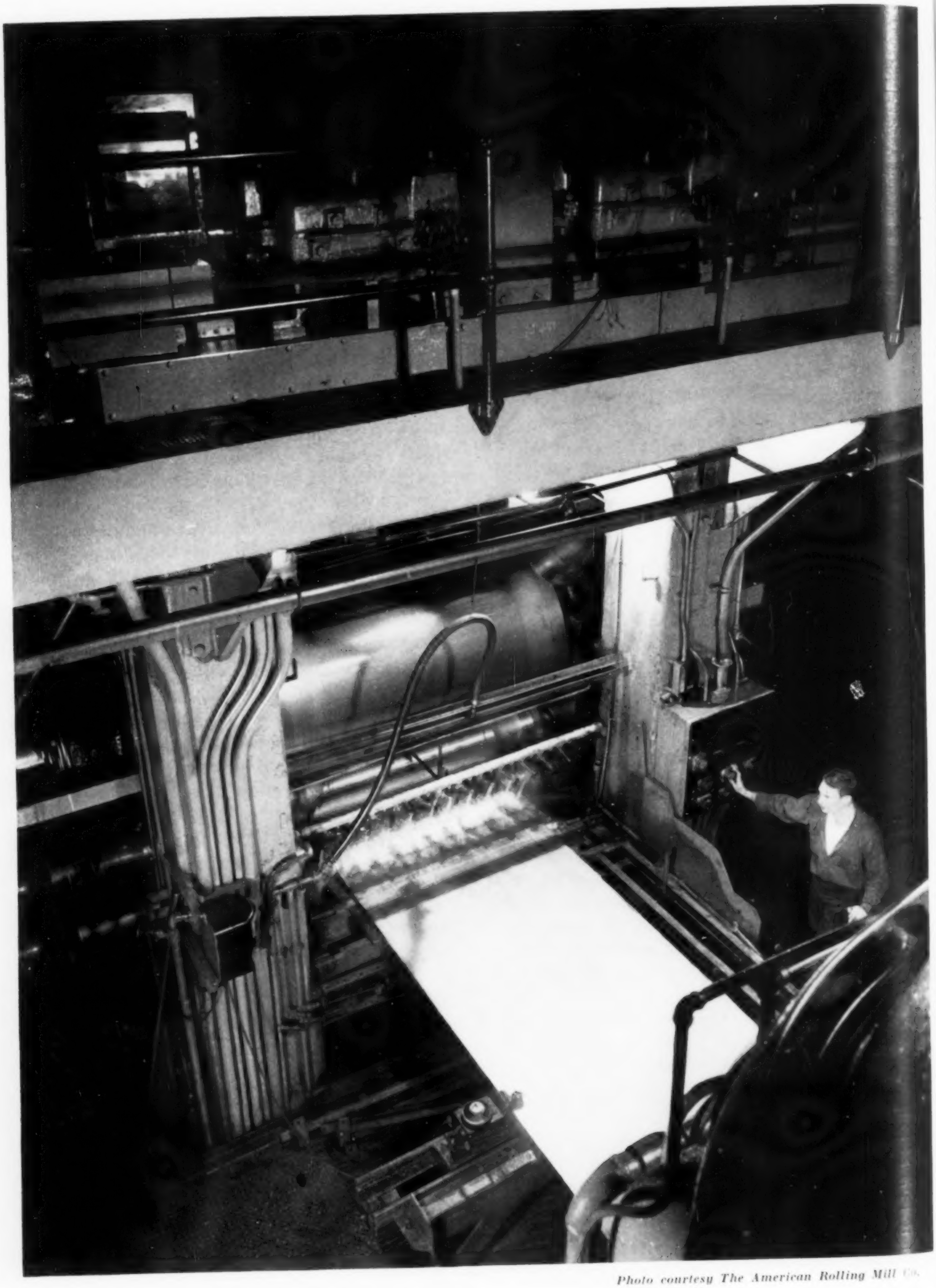


Photo courtesy The American Rolling Mill Co.

MAKING SHEET STEEL

to fit the

requirements

By R. S. Burns
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The American Rolling Mill Co.
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SHEETS AND STRIP ARE COLD REDUCED to the desired thickness most usually from broad strip in coils on a stand or stands of rolls with power driven reels. The reasons for cold reduction are:

1. To obtain the desired surface finish.
2. To impart the desired physical properties.
3. To obtain better gage uniformity from end to end and from side to side of the sheet or strip.

The amount of cold reduction performed will be discussed later, but suffice to say now that it is governed largely by the application under consideration. For example, sheets and strips for drawing applications are cold reduced anywhere from 30 to 70% depending on the part to be made and the method of making it (die design, etc.); tinplate may be reduced as much as 90%, depending on the limitations of the hot strip mill. Increasing amounts of cold reduction will tend to make the resulting sheet finer grained and harder after annealing.

Equipment for cold reduction is available which makes use of the following applications of power to effect the desired reduction:

1. All power applied to the working rolls.
2. All power applied as forward and back tension.
3. Power applied partly to the working rolls and partly as forward tension.
4. Power applied to the working rolls, also as forward and back tension.

Sheet and strip steel for deep drawing applications is a product of highest quality so an essential consideration is quality control.

Analysis—Steel used for difficult stampings is generally of the rimming type with an analysis in the following range: Carbon 0.04 to 0.10%, manganese 0.20 to 0.45%, all other elements as low as possible.

The analysis will depend to a great degree on the methods selected for manufacture of the sheet, and the drawing or stamping hazards which the sheet must undergo. While we show a range for carbon and manganese above, it must be remembered that, from heat to heat of the same intended analysis, carbon may be controlled to within 0.01% and manganese to within 0.05%. In casting of an ingot within the composition given there is a segregation of some of the elements which must be taken into consideration in selecting the method of rolling and processing. The first illustration and its accompanying tabulation, on the next page, indicates the amount of segregation that is sometimes obtained in a rimming steel ingot. Segregation will be seen in the figures for carbon, sulphur and copper, which are all potent hardeners.

Annealing—After sheets have been reduced to gage by any of the methods mentioned above, they are then ready for processing, the first operation of which is ordinarily some kind of an anneal. If the sheets are reduced to gage at temperatures below the recrystallization temperature (as they are on the sheet bar finish-

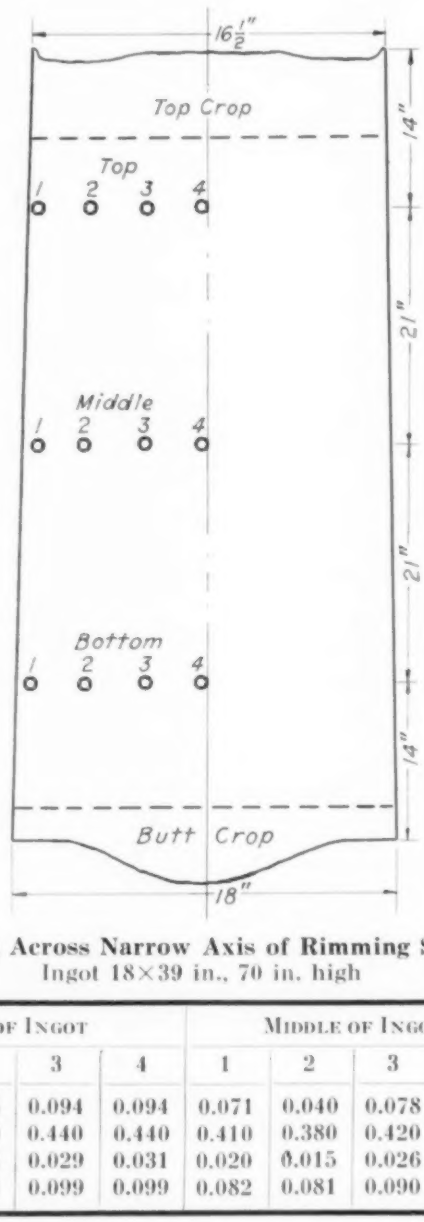
ing mill or cold reduction mill) the grain structure is fragmented by the plastic deformation and some kind of an annealing operation is necessary to restore desirable physical properties. In general, there are three annealing operations used in sheet and strip production:

I. The normalizing operation, which consists of heating the sheet to a temperature above the upper critical or A_3 point (approximately 1650° F.) and cooling to room temperature. This recrystallizes and refines the grain structure through the medium of the transformation of alpha into gamma iron — and the reverse, on cooling. The normalizing operation is utilized to the greatest extent on hot reduced material to produce improved drawing properties, because in many cases a box annealing would result in critical grain growth arising from the low residual strain in the hot-reduced product.

Likewise material with a low residual strain is very apt to produce material with coarse grains if the normalizing temperature is not reached during annealing or if the material is not held at normalizing temperature for a sufficient length of time to effect the transformation. In the normalizing operation the sheet producer has another opportunity to tailor his product according to the customer's demands. He can vary his normalizing temperature and heating and cooling rates — the effects of such variations are shown in the three micrographs, at top of page 305, which in general indicate that the slower the cooling rate through the critical range the larger the grain size. While most of the product which is normalized has been rolled on a hot mill, cold-reduced sheets may also be normalized when it is so desired.

II. The stress relieving anneal. This annealing operation is a low temperature pack or box anneal, utilized to soften the sheets and to improve the drawing qualities by removing the internal stresses produced in rapid cooling in the normalizing operation, or in leveling or light rolling operations after normalizing. The temperature of this anneal is in the range of 950 to 1200° F.; a protective atmosphere can be used under the cover to prevent oxidation, or the charge may be steam blued as desired.

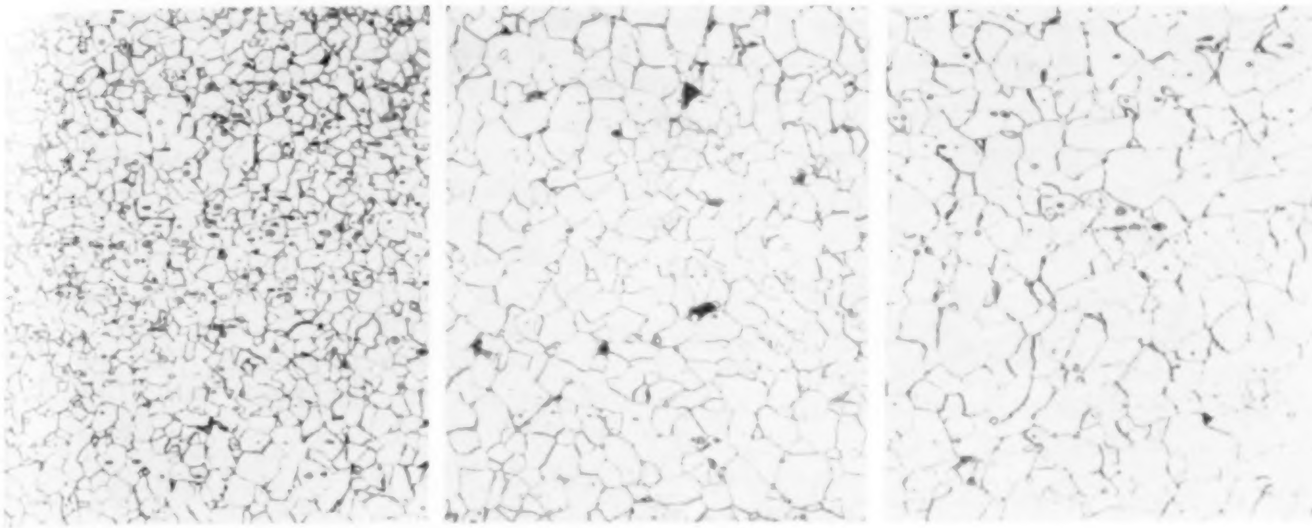
III. The cold strain, low temperature recrystallization anneal may be used on steel cold reduced in excess of 30%. This annealing is carried out by placing the stack of sheets or coils on a bottom plate and covering the pile. The charge is then heated to the desired temperature (this may vary from 1200 to 1400° F.) and allowed to soak until the temperature is uniform throughout the charge, after which it is allowed to cool to 200 to 300° F. before uncovering. Material that has been cold reduced or descaled before annealing is usually so annealed in a protective atmosphere in order to prevent the formation of oxide on the sheet during the annealing cycle. This protective atmosphere is ordinarily produced by partially burning natural gas or butane to a composition that is slightly reducing to iron but which will not break down further and deposit carbon at the annealing temperature. Material that is desired with an oxide finish is either annealed without the protective atmosphere or is steam



Segregation Across Narrow Axis of Rimming Steel Ingot
Ingot 18×39 in., 70 in. high

Element	Ladle Analysis	Top of Ingot				Middle of Ingot				Bottom of Ingot			
		1	2	3	4	1	2	3	4	1	2	3	4
Carbon	0.086	0.070	0.036	0.094	0.094	0.071	0.040	0.078	0.079	0.058	0.041	0.062	0.060
Manganese	0.410	0.420	0.370	0.440	0.440	0.410	0.380	0.420	0.420	0.400	0.380	0.380	0.380
Sulphur	0.018	0.023	0.016	0.029	0.031	0.020	0.015	0.026	0.026	0.016	0.014	0.022	0.013
Copper	0.081	0.083	0.078	0.099	0.099	0.082	0.081	0.090	0.091	0.084	0.084	0.091	0.090

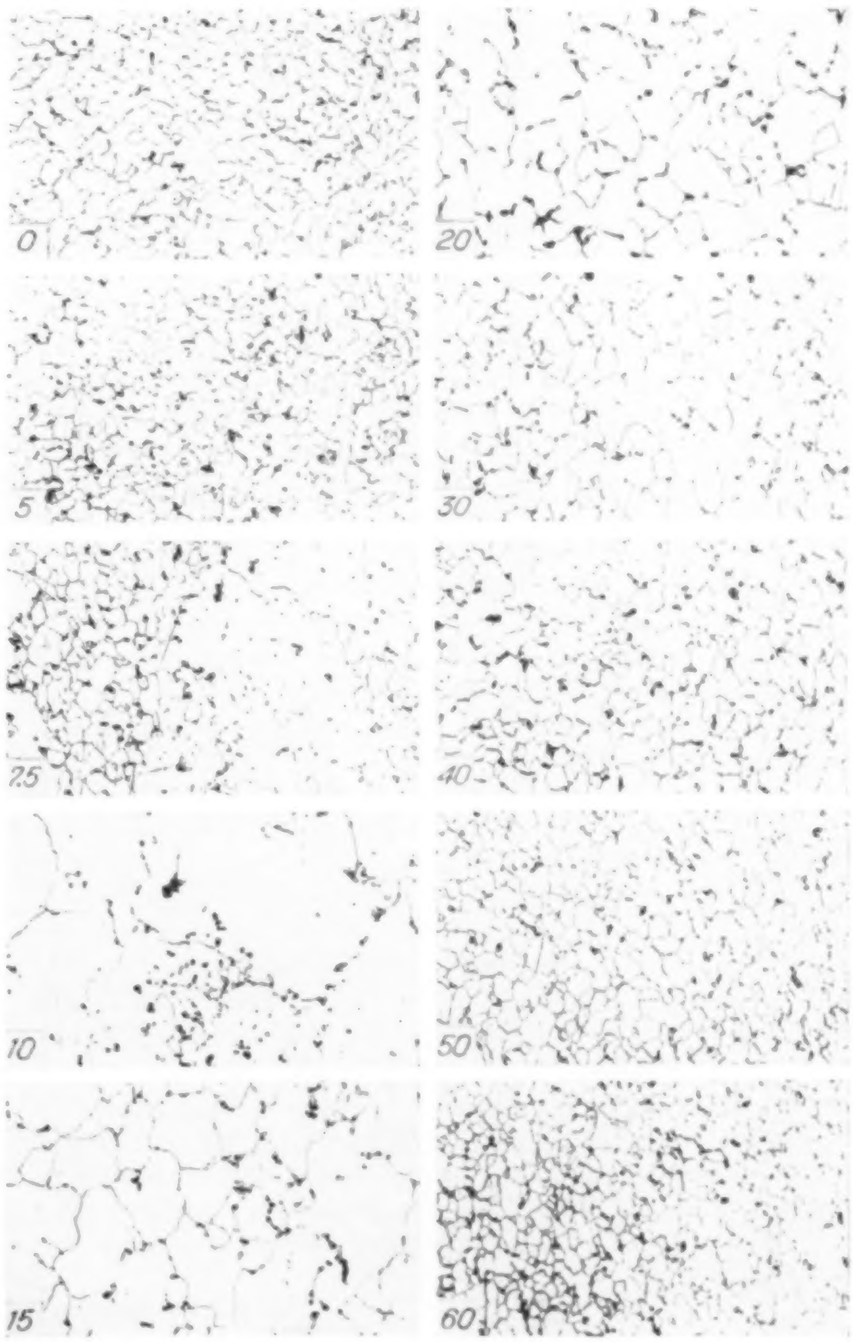
Cooled 185° F. per Min. | Cooled 44½° F. per Min. | Cooled 30° F. per Min.



Typical Grain Structure of Normalized Mild Steel Sheets Cooled at Various Rates. × 100

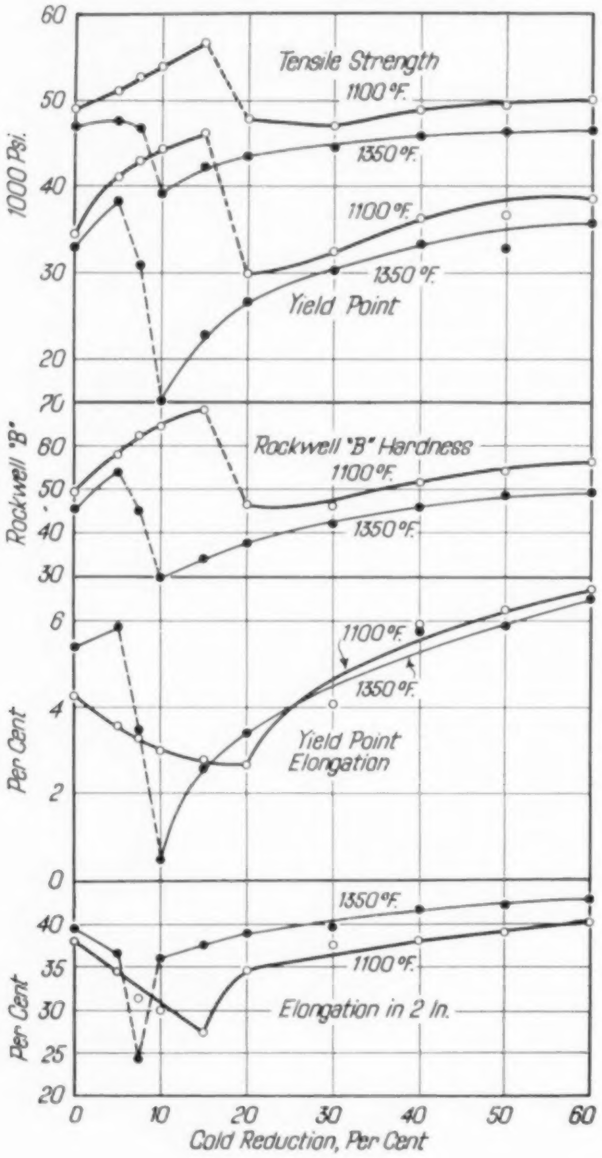
blued by adding steam under the cover after the temperature has dropped to about 1000° F.

Rolling Schedule — In the production of sheets for drawing purposes, the metallurgist again has an opportunity to tailor his product by varying the amount of cold reduction before this low temperature recrystallization or process anneal. In adjoining illustrations we will attempt to show what variations in grain size and physical properties can be produced by different amounts of cold reduction before annealing at 1100 and 1350° F. As will be noted in the large group of micrographs at right, a cold reduction of at least 30% is generally necessary, if the next operation is to be a box anneal at 1200° F. or higher, in order to avoid the production of extremely coarse-grained material that is unsuitable for any forming requirements. These micros show clearly the effect of the amount of cold reduction ahead of annealing on the grain size of mild steel annealed at 1350° F. The effect of variations in the amount of cold reduction on physical properties for annealing temperatures of 1100 and 1350° F. is



Microstructure of Mild Steel Cold Reduced Various Amounts as Noted, and Box Annealed 4 Hr. at 1350° F. and Cooled 25° F. per Hr.

Tensile Properties of Mild Steel Sheets Cold Reduced Various Amounts and Box Annealed at 1100 and 1350° F.



shown in the first set of curves alongside. The sharp breaks exhibited in the property curves between 5 and 20% cold reduction are due to the uneven coarse grain caused by a critical amount of strain before box annealing.

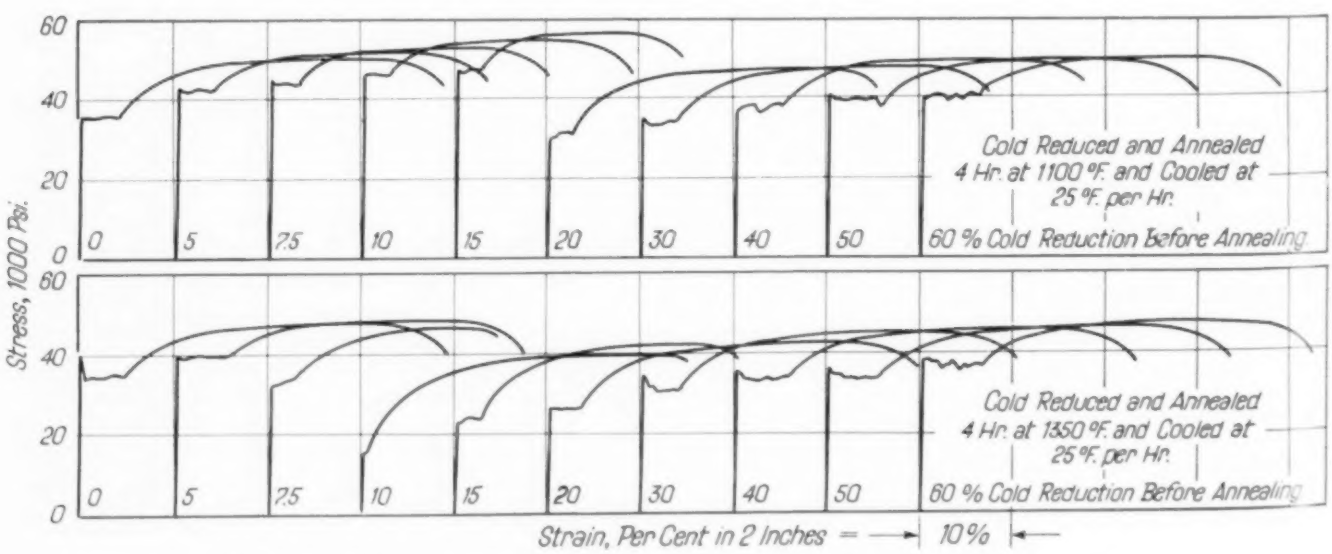
These breaks indicate an unstable condition existing below 30% cold reduction in which the hardness, grain size and elongation are practically unpredictable, because they are so dependent on the amount of cold reduction and the annealing temperature. The group of stress-strain curves shown on the bottom of this page for mild steel receiving various amounts of cold reduction before box annealing at 1100 and 1350° F. are revealing. Note that in the coarse-grained material which received 10% cold reduction and an anneal at 1350° F. (fourth curve in the lower line) the yield point elongation is practically zero. Note also that these stress-strain curves show the increase in yield point with increasing amounts of cold reduction above the critical strain region.

In selecting the amount of cold reduction to be used, the sheet mill metallurgist is governed by:

1. The severity of the drawing operation.
2. The surface requirement both in the severely strained and undisturbed areas of the stamping.
3. The analysis of the steel to be used.
4. The annealing cycle to be used.
5. The limitations of the hot and cold strip mills.

As stated previously, the figure usually arrived at by weighing all of the different factors is somewhere between 30 and 70%.

Finishing — One of the most fundamental sources of information which is broadly applicable to drawing behavior and determination of drawing



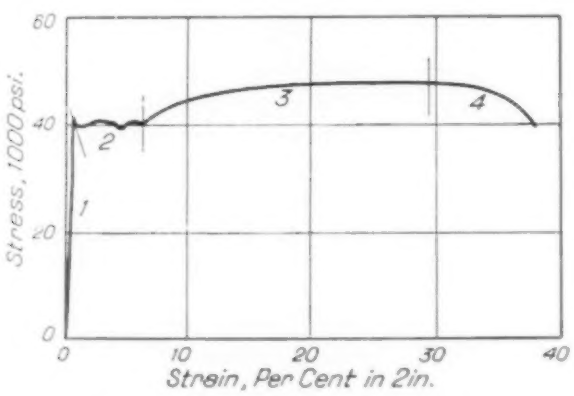
Effect of the Amount of Cold Reduction Before Annealing on the Shape of the Stress-Strain Curve for Mild Steel, After Box Annealing at 1100 and 1350° F.

ality and to the metallurgical effects obtained in temper rolling, roller leveling, and like operations, is the stress-strain or load-deformation diagram obtained in tensile testing. For discussion, a diagram of this kind is shown below as obtained from fully annealed material. It can be divided into the following portions:

1. Elastic deformation.
2. Yield point elongation.
3. General elongation.
4. Localized reduction of area.

The amount of elastic deformation up to the yield point for dead soft mild steel is of the order of 0.10%.

The yield point elongation region constitutes the wavy portion of the diagram immediately following elastic deformation. This portion of the stress-strain diagram is one of great practical importance both in forming operations and processing of the steel before shipment. It is also of very great metallurgical interest due to the obscurity of the mechanism by which it occurs. It has been shown that the depth or severity of stretcher strain is dependent on the amount of yield point elongation. Hence, in order to elminate stretcher strains we must eliminate the yield point elongation from the stress-strain curve. The method used for the prevention of stretcher strains usually consists of subjecting the steel to small cold reductions (up to 2%) by rolling on a temper mill. The right hand diagram above, taken from a publication by Curtis, Kenyon and Burns, illustrates the effect of temper on the stress-strain curve.



Typical Stress-Strain Diagram of a Dead Soft Steel Sheet Shows Characteristic and Sudden Yield

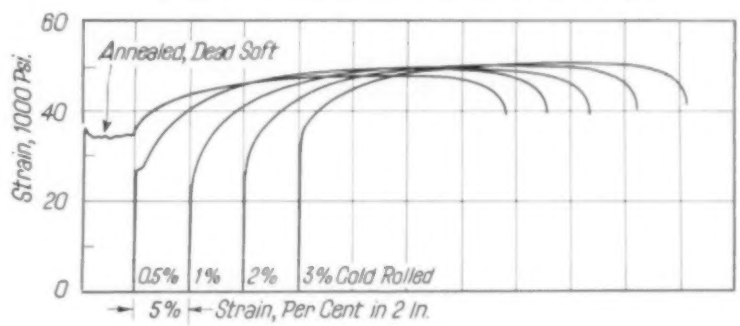
Some of the more important observations in regard to effects of types of temper mills and metallurgical characteristics of the material on the amount of temper necessary to eliminate strain are:

1. The smaller the grain size of the steel, the greater the yield point elongation and the greater the amount of temper rolling necessary.

2. Sheets with polished or smooth surface with the same yield point elongation require more temper rolling than do sheets with dull surfaces.

3. The smaller the rolls used for tempering, the smaller the amount of reduction necessary.

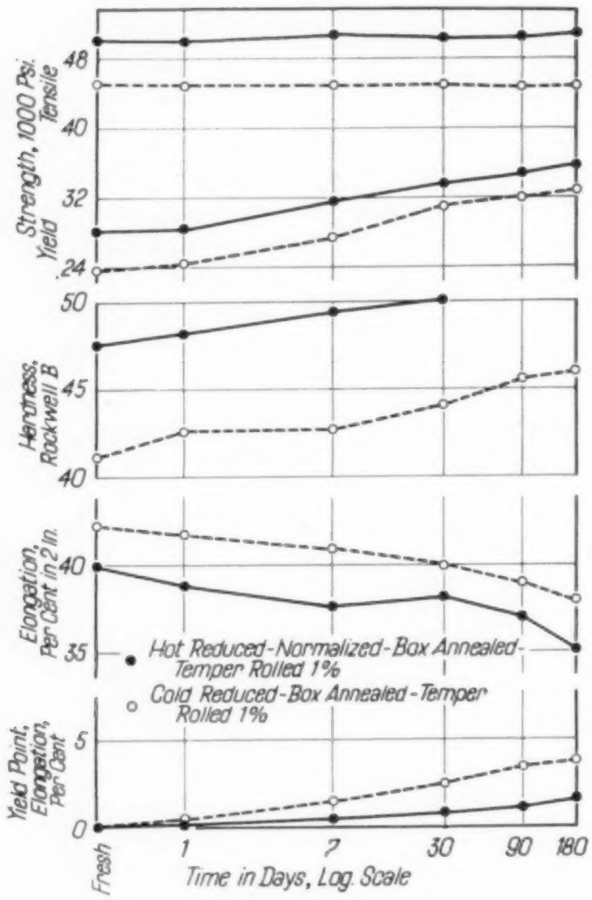
Stress-Strain Curves of Normalized, Box Annealed Mild Steel Sheets, Temper Cold Rolled 0, 0.5, 1, 2, and 3%, and Tested Fresh



Unfortunately, temper rolling, while eliminating the yield point elongation and also the tendency to stretcher strain, when performed in increasing amounts, also increases the hardness and decreases the ductility. Still more serious, it sets off the tendency to *strain-age* which further deteriorates the physical properties with time. A measure of this tendency is as follows: When a piece of annealed low carbon steel is tested in tension, the stress-strain curve, as we have shown previously, exhibits a definite discontinuity at what is called the yield point, just as the deformation changes from that which is elastic to that which is plastic. Ludwik and Scheu showed that if the load is released after this point is passed and the specimen is immediately reloaded, the curve rises at once to the former load value before plastic deformation again begins. However, if the piece is set aside after straining through the yield point, and the test not resumed until several weeks or months later, the yield point will again be observed but this time at a higher load than before.

Ordinary mild steels age very rapidly with respect to this yield point behavior. Annealed material exhibits this irregularity in the stress-strain curve, cold working obliterates it, and aging causes its return. The heavier the cold work, the longer the time necessary for the return of the yield

Typical Stress-Strain Curves for Normalized, Box Annealed Mild Steel Sheets, Cold Rolled 1% and Aged at Various Temperatures



point. The yield point phenomenon itself has been the subject of considerable study aside from its connection with aging. Various theories have been proposed to explain it, but none has received general acceptance.

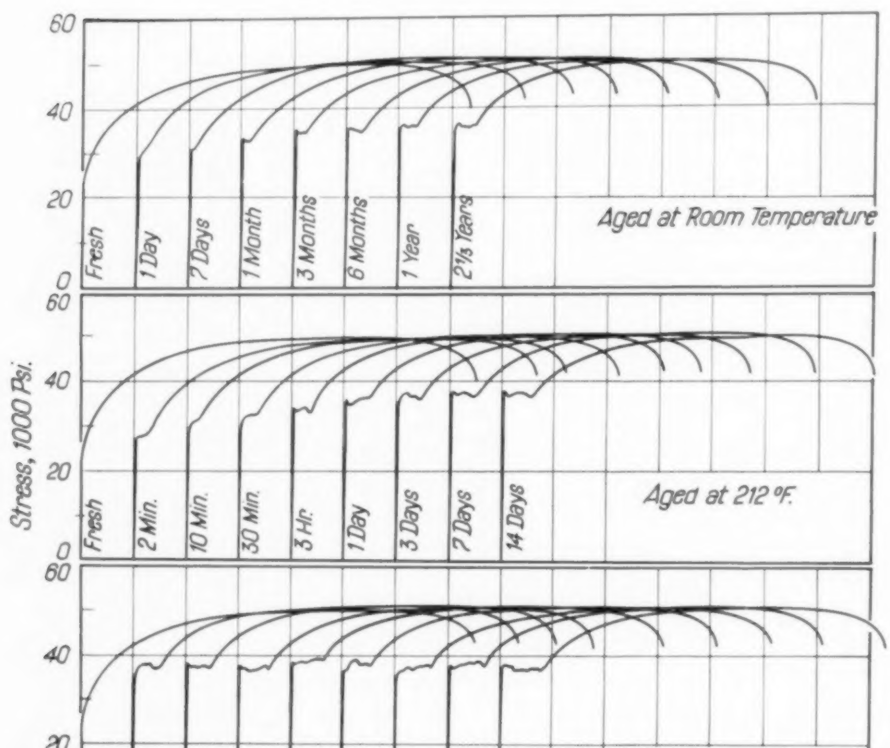
At any rate, the tensile test has been used effectively to study the aging behavior of mild steel sheets. The lower figures on this page show the return of the sharp yield point in the stress-strain curves of annealed mild steel sheets which had been cold rolled 1% and then aged at three different temperatures. It is apparent that as the temperature increases, the time required for the return of the yield point diminishes. The yield point elongation also increases in magnitude as aging proceeds.

With this in mind, it is customary for the mill to temper roll an amount slightly greater than the minimum amount necessary to prevent the sheets from stretcher straining when used within a reasonable period of time. If sheets are temper rolled too large an amount for the job being considered, excessive breakage is imminent. The amount of temper is usually specified as a certain percentage of elongation of the annealed sheet and is generally of the order of from 0.3 to 3%. Measurements are taken throughout the lift of sheets being rolled, by temper roll checkers attached to the metallurgist's staff.

The set of curves at top left show the effect of various agings at room temperature on the hardness and tensile properties of mild steel made (1) on a hot roll normalize routing and (2) on a cold reduced box anneal routing.

We have dealt with the manufacture of steel sheets by several different processes, of which the essential difference, insofar as metallurgical characteristics are concerned, is in the manner in which the sheets have been reduced to gage and then annealed. Aside from economy and improved surface, the most modern practice of cold reduction to gage followed by annealing has another great advantage over the older processes requiring both normalizing and annealing. This advantage is in the improved physical properties

(Continued on page 366)



Mild Steel Sheets, Either Box Annealed or Normalized, Harden Gradually and Lose Ductility After Temper Rolling

QUICK, WATSON, THE MICRO

examples of metallurgical detection

By R. M. Brick
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THE MATERIAL IN THIS ARTICLE (AND possibly some succeeding ones) was used as illustrations in a six-lecture educational course presented by the New Haven Chapter during the autumn of 1940 on "Service Failure Investigations". As a come-on the course was billed "How to Be a Metallurgical Detective".

I. The Case of the Pitted Clutch Parts

A few specimens from a batch of several thousand clutch parts destined for use in radial aircraft engines were brought to the Hammond Laboratory one day. The metal parts, supposedly of S.A.E. 52100 steel (1% carbon, 1¼% chromium) and about ¾ by ½ in. in size, had been heat treated in a salt bath to a Rockwell hardness of C-58 to 60, and then burnished to a bright finish by tumbling in a barrel. Examination with a binocular microscope disclosed small but deep pits over the entire surface and small chipped spots on the edges and corners.

The circumstances may soon become familiar: A small but expanding machine shop had a sub-contract from an aircraft engine manufacturer. This shop, taking S.A.E. 52100 rod stock supplied by the engine producer, machined the parts to finished dimensions on automatic equipment, sent them to an outside heat treating shop and specified the hardness desired. After hardening and tempering (in a salt bath so as to avoid scaling or decarburization), the parts were burnished and the defective surface then became apparent. As is usual in these cases, the machine shop operator felt certain he had been given the wrong steel and wanted a chemical analysis of the stock.

Most physical metallurgists are as averse to running chemical analyses as the usual city detective is to pounding a beat. The aversion of the metallurgist has more of a basis than sheer laziness, since service troubles are seldom solved by routine analyses. In this case, one of the points which led the machinist to suspect he was working with the wrong steel was the greater tool wear encountered with present stock as contrasted to previous supplies. The reason for this became clear when it was learned that former stock had a ground finish whereas the present material was received with a scaled surface.

The microstructure of this stock, Fig. 1, was that of a normal spheroidized high carbon steel. When heated to 1700° F. and furnace cooled, its

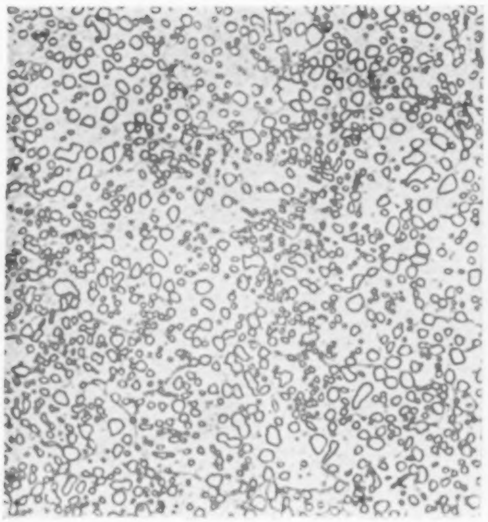


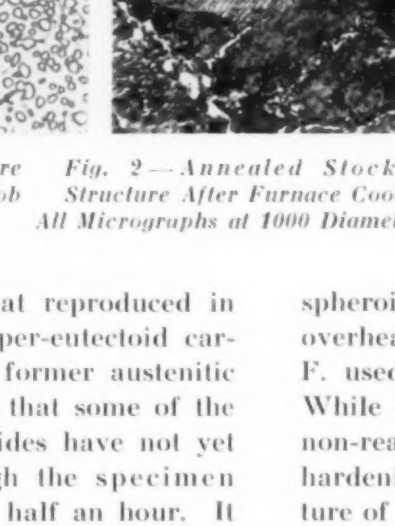
Fig. 1 — Spheroidized Structure of Bar Stock Furnished for Job

Fig. 2 — Annealed Stock; Hyper-Eutectoid Structure After Furnace Cooling From 1700° F.

Fig. 3 — Coarse Martensite in Clutch Parts. Rockwel

All Micrographs at 1000 Diameters, Etched With Nital

structure was changed to that reproduced in Fig. 2, pearlite with thin hyper-eutectoid carbide envelopes outlining the former austenitic grain boundaries. Note also that some of the previously spheroidized carbides have not yet completely dissolved although the specimen was held at temperature for half an hour. It seemed fairly certain on the basis of these pictures that the steel *was* S.A.E. 52100, for a plain carbon steel would have had to contain more carbides than are apparent in Fig. 1 to give the structure shown in Fig. 2. The presence of 1% chromium, however, reduces the carbon content of the Fe-Fe_3C eutectoid (pearlite) enough to account satisfactorily for the two structures.



Having established the probability that the original steel was of the specified analysis and normal structure, the actual clutch part was examined metallographically. Its heat treated structure is reproduced in Fig. 3. This martensite is extremely coarse, well adapted to demonstrate to students the true nature of the martensitic structure but certain to show poor service properties. The length of the needles suggests the very large austenitic grains in which they originated. Note also the absence of residual or undissolved spheroidal carbides. Both facts indicate an overheated steel, undoubtedly above the 1700° F. used in obtaining the structure of Fig. 2. While the conditioned salt bath was probably non-reactive with the steel surface at normal hardening temperatures, at the high temperature of 1750° F. or even more, it did apparently cause deep pitting (although no appreciable decarburization was noted). The inherent brittleness of the coarse martensite caused chipping of the edges during barrel burnishing.

To demonstrate the proper structure, some of the original stock was quenched in oil from 1550° F. and drawn at 390° F. to a Rockwell hardness of C-58. The microstructure, Fig. 4, showed a very fine, unresolvable martensitic matrix of maximum toughness, and residual carbides for necessary wear resistance.

Thus the case of the pitted clutch parts was solved without undue loss of shoe leather or time. The overheated pins could not be reclaimed because of dimensional requirements and the difficulty or expense of changing the structure (requiring first a spheroidizing anneal and then rehardening). Subsequent production is being hardened in controlled atmosphere furnaces under proper temperature conditions and no further troubles have been encountered.

"Simple, my dear Watson, indeed elementary enough for the police detectives."

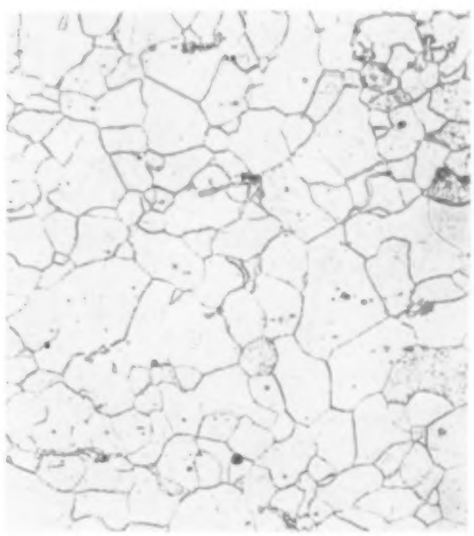
Fig. 4 — Unresolved Martensitic Structure Containing Carbide Particles in Stock Properly Treated to Same Hardness as Fig. 3

II. The Case of the Backward Clock

A manufacturer of electric clocks found that while most of his products managed to keep up with the rotation of the earth about its axis, about 10% of them were backward and lost from 5 to 30 min. a day. While it is sufficiently mysterious why any clock should run at all, it was determined to study the minor mystery of why some of them should be so far out of step. Eventually a metallographic examination of the motor parts in a good clock and in a backward or time-losing one was initiated to see if a difference in the metal parts could be responsible.

The soft iron pole pieces of both clocks were identical in having a single phase ferritic structure with similar grain sizes. Figure 5. Next an unhardened stamping of 0.95% carbon steel in the rotor of each motor was examined. Somewhat finer spheroidal carbide structure was found in the section from the good motor, Fig. 6, as contrasted to that from the poor one, Fig. 7, but this seemed a rather minor difference. However the same high carbon steel was also present in each motor in the hardened condition and that from the good clock showed a normal hardened structure like Fig. 4 of the pitted clutch, with a few undissolved carbides in an unresolved martensitic matrix. The section from the time-losing clock, however, showed an extremely coarse martensite with no residual carbides (like Fig. 3).

Fig. 5 — Structure of Soft Iron Pole Pieces Was Uniform in All Clocks



In the backward clock the brittleness and poor wear resistance of the overheated structure were probably not factors in the problem. Perhaps it was the altered magnetic characteristics that caused this clock to lose time. At any rate, the examination disclosed a general lack of control or knowledge of proper heat treating temperatures that resulted in non-uniform parts and a rather high percentage of unreliable assemblages. The manufacturing conditions were corrected before the public lost confidence in this particular brand of clock (as reflected in a loss in sales volume).

Next month: Troubles with a different source, to show how microstructures and related data enable a metallurgical detective to visualize the prior history of a defective metal part.

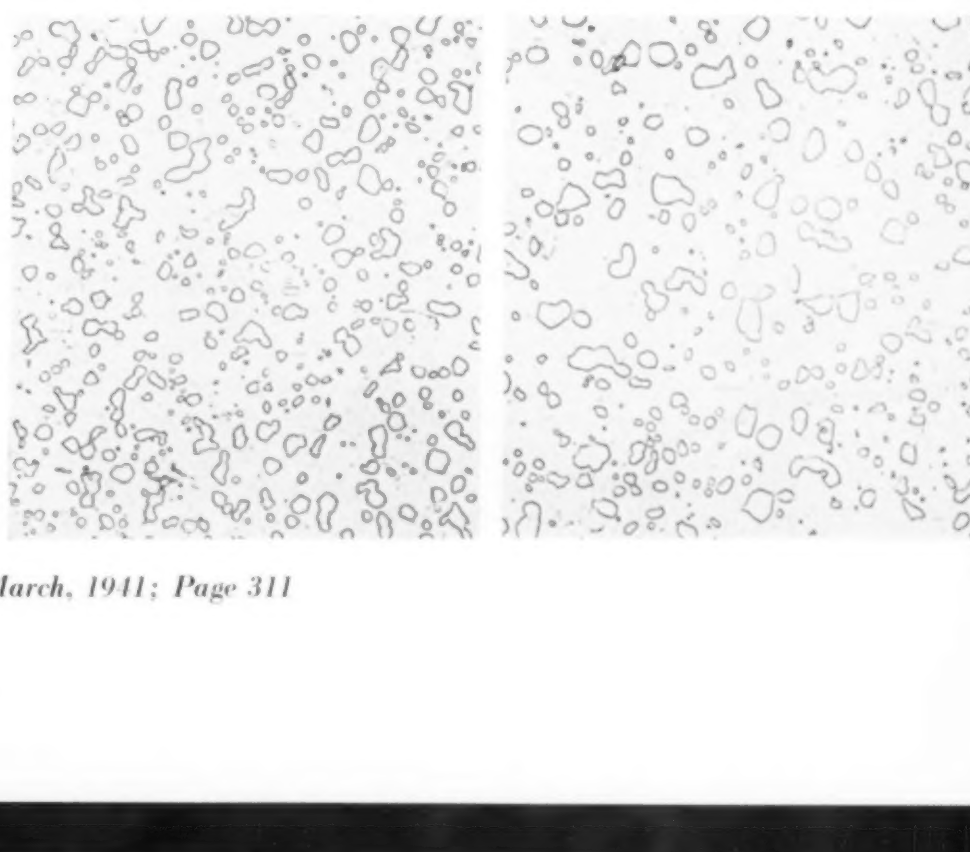


Fig. 6 (Left) and 7 — Spheroidized Structures of Unhardened Rotor Sections in Good Motor (at Left) and in Motor That Lost Time

CRITICAL POINTS

by the editor

BELIEVING THOROUGHLY that a technical editor should be blood brother to an educator in ideals and accomplishments, was at home with FRANK MALICK, vocational director of the Canton Schools, while inspecting the newly built vocational high school given by H. H. TIMKEN. Each shop for the boys was a model in arrangement and modern equipment, and presumably the girls studying cosmetology ($5 word for hair dresser), cookery, needlework and the various feminine arts have equally well-equipped labs. Only those ninth-graders are enrolled who are not candidates for college and who pass aptitude tests. In the ninth and tenth grades the "regular cultural" studies are offered, although general survey courses in mechanic or feminine arts enable the boy or girl to select a future specialty.

Beginners, Training for a Job

Even then, no more sheet metal workers (for instance) are enrolled than the surrounding industry can absorb. In the eleventh and twelfth grades, 50% of the time is in shop and formal instruction for the chosen trade, say sheet metal work, 30% on allied subjects (such as heating and ventilating, in this case) and 20% on "cultural". To an old-fashioned advocate of the idea that public school education should emphasize matters of the mind and spirit rather than handicraft, it was disturbing to find that industries and trades organizations have so abdicated their responsibilities for the training of future personnel; a partial consolation is the conviction that the preparation for a beginner's job is now being well done — at least in Timken Vocational High School. (Auxiliary note: Warner & Swasey, Cleveland manufacturer of machine tools, that has long operated a notable training plan for mechanics, has announced that this phase of its preparedness program is being assumed by near-by Fenn College.)

AT ANOTHER END of this educational scheme, talking with CHARLES MACQUIGG, Dean of Ohio State's Engineering College, who heads a committee attempting to increase the use and value of research in the "land-grant colleges" — not in the agricultural experiment stations, which have long been carefully nurtured by a benign Congress to the present annual sum of seven million, but to the corresponding engineering experiment stations which subsist on meager contributions from the States and industry. One can agree thoroughly with him that, given the necessary public support and financing, the engineering faculties and equipment in the 40 or more land-grant colleges are capable of much useful and really imperative work in these rushing days when industrial and endowed research organizations are unable to take on new problems.

A Sadly Neglected Resource

One can also view the notable improvements in American agriculture and husbandry, stemming from the continuous work in the agricultural experiment stations, and comment ruefully on the corresponding contributions the engineers could have made to American economy had they been similarly encouraged.

TO THE CANTON PLANT of United Engineering and Foundry Co., where K. F. SCHMIDT, metallurgist, told of improved foundry practice that turns out sheet mill rolls good for double the tonnage as compared with the performance which brought letters of commendation from the early continuous mills. The "air furnace"

Air Furnace Iron for Large Rolls

or melting the iron look like small copper reverberatories, being fired by pulverized coal and equipped with waste heat boilers. (JOHN QUINN, manager, says the economics of this arrangement are none too clear; a steady flow of power cannot be had from the four furnaces, even when the plant is busy, due to normal fluctuations in the melting program; the boilers require maintenance and the draft must be boosted with power-consuming fans, and the power plant to operate on variable steam supply requires much stand-by equipment with corresponding capital charges.) These air furnaces are arranged side by side alternating with slag pits and charge-car tracks. An overhead crane removes the roof in three large self-supporting sections ("bungs") and places a new charge of 30 tons of pig and scrap and the furnace is again under fire in as many minutes. Worn out rolls are favorite scrap; strangely enough a 15-ton block melts without delaying the normal 7-hr. heat. Melting is rapid, alloys are added, and metal tapped as soon as the laboratory says "go ahead".

15-Ton Cylinders With Perfect Surfaces

STEEL MILL ROLLS are solid cylinders and are cast with axes vertical. The mold is an assembly of massive iron rings, some sand lined, others merely washed and acting as chills. The bottom section has one or two tangential gates, depending on the mass to be cast, and the entering metal is thus given a moderate swirling motion, generating enough centrifugal force to exclude dirt particles from the surface regions. An ingenious method of casting "duplex" rolls consists of filling the mold entirely with a high alloy mixture at such a rate that a shell about 1½ in. thick solidifies against the chill, and then continuing with enough low alloy iron so the latter, rising up in the mold, pushes out ahead of it all the unsolidified high alloy into a catch basin. As SCHMIDT says, it's all a matter of rate and timing — presumably just like a golf swing, and just as easy for any but a professional to do perfectly every time! Some day some fascinating metallurgy will be written about roll manufacture. Prior to the advent of alloy mixtures the art was to select iron with proper chemistry and inherent characteristics, melt it at such temperature and rate that it would solidify with the correct "grain" or chill — a macrostructure easily visible on the freshly machined surface — and with nodular rather than flake graphite. Chilled working surfaces were, of course, full of hard cementite — undecomposed iron carbide. More recently the advent of molybdenum, nickel and chromium as alloys, singly or in various combinations, has modified the microstructures considerably. Hardness and wear resistance at the necks is not the same if the roll is to have roller bearings rather than bronze or lignum boxes. Still the body must have "grain" for strength and toughness, even though the wearing surfaces are so highly alloyed as to be air hardening (hard from martensite rather than from massive cementite). Withal no physical defect, discoverable on the ground surface under a magnifier, is tolerated.

60-Ton Electric Furnace Is Economical Size

SURPRISED TO FIND that four years had elapsed since last visited Timken Steel and Tube plant in Canton — a relatively frequent port of call because WALTER HILDORF and his associates can always give you some new and stimulating metallurgy. Capacity of the electric steel department is currently being expanded 7500 tons per month to a total of 29,000. Experience with furnaces ranging from 10 to 100 tons indicates that (for them) the 60-tonner is most economical, being about the largest that can be hand rabbled, and almost the optimum for electrode, refractory, power, and labor requirements. From remarks dropped by GILBERT SOLER, manager of mill research, the uses of electric steel will have to be broadened after this emergency, to supplant a portion of the openhearth product. VAN FISHER's notable photographs made for METAL PROGRESS in this plant in 1936 show ingots cast with refractory hot tops. These brick collars cost about $1 each, and the bats must later be cleaned up; many of these are being replaced with Charman and Darlington permanent hot tops. These are steel collars 20 in. high that slip into the mold top; they are lined with insulating brick that last about 60 casts. Before each use they are plastered with graphite-clay slurry, and a thin steel gasket ingeniously fastened underneath to chill any liquid steel that would work up between mold and floating hot top. Some careful planning will enable the present blooming mill to handle the enlarged tonnage . . . . . Amsler-Morton soaking pits are

to replace the present battery, experience with one having already indicated that the automatic control of combustion and temperature not only saves fuel but reduces scale losses. Much controlled cooling of ingots, blooms and mill-rolled rods is done in appropriate insulated pits.

Controlled Cooling in Rolling Mill

Ingots of sensitive steels like the Krupp nickel-chromium analysis must be carefully cooled to avoid "flakes", and later their blooms carefully cooled to avoid "thermal bursts". Proper cooling from the bar mill (requiring as much as 72 hr.) will improve among other properties the cold shearing of forging billets — that is, enable them to break off sharply without dog ears . . . . . In the finishing end of the tube mill found half a dozen Newberth tube reducing machines, like the ones used on the tougher copper alloys and illustrated in February METAL PROGRESS (page 187). These can maintain concentricity better than draw benches and make a much larger reduction without "exhausting the ductility" and requiring a process anneal. A Newberth machine can knead 52100 tubing up to a Brinell of 269, whereas about 229 is the danger point before breaking in a draw bench, and the harder metal is correspondingly improved in machinability.

THIS BLASE OBSERVER of mass-production operations experienced new thrills when inspecting the foundry at the Rouge plant in Detroit. Piloted about by various members of Ford's metallurgical staff, he was at times stunned by the concentrated activity on all sides, where men and machines are packed together so close, yet so well organized that no one is in another's way.

Special Steels and Irons in Ford's Foundry

Most of the molds look more like assemblages of cores than anything else; these cores are made in a continual stream on production lines, some of them to such high accuracy that the steel core boxes have Ames gages permanently attached to make sure the diameter is held correct to thousandths. No less than 26 electric furnaces are installed, either to melt stock for alloy steel castings or to superheat molten iron from cupolas or blast furnace mixers. Rapid chemical analyses are essential to avoid delays in this smoothly balanced operation; it must be seen to appreciate the necessity for spectrographic quantitative analyses, as done in the compact and efficient laboratory described in these columns, July 1939 issue. Seemingly each important part has its own perfected analysis — be it copper-silicon steel for crankshafts or chromium-nickel-silicon austenitic steel for exhaust valves, low alloy gray iron for cylinder blocks or a quick-annealing malleable for lugs. Such a wide variety indicates that a trend toward diversity in the cast irons and steels is counteracting the opposite trend toward simplification of the list of carbon and alloy steel sheet and bars from forge and rolling mill.

TO THE ANNUAL MEETING of the American Institute of Mining and Metallurgical Engineers, and to me the high spot was some unscheduled and salty remarks by JOHN UNGER, dean of the Steel Corp.'s metallurgical staff. (He, by the way, was inducted into the Institute's Legion of Honor, by virtue of a half-century's membership.) During a steel session, Chairman GRAHAM, proponent of Jones & Laughlin's photocell flame-control, remarked that bessemer steel was now being produced in America at the rate of seven million tons a year, double that of two years ago, and there was still more ingot capacity available if the rolling mills could handle it.

Bessemer Redivivus

While there were no stenographers or reporters present, it is recalled that Mr. UNGER then had something pertinent to say about the real influence of such elements as phosphorus, sulphur and copper in steel — elements whose presence in ores from the iron ranges caused the openhearth to supplant the bessemer because the latter could not eliminate them, yet today 0.25% or more of each is added to steel, on occasion, for its definite improvement. . . . American steel must be made cheaper, not only because of political pressure to hold the selling cost down, but also to counteract rising labor costs and taxes, as well as to compete with the "featherweight" metals and plastics. Cheap pig iron, the source of cheap steel, can come from plentiful supplies of ore, a little too high in phosphorus unless the phosphorus is applied in its true role as a useful hardener. A 50-ton converter, perhaps with hot blast, making at least three heats per hour, can turn out as much good steel in a day as ten 100-ton basic openhearth furnaces, and the plant costs one-third as much to build. Here is good steel from cheap iron, a cheap process and a cheap plant.

WEAR AND SCUFFING

of cylinder

bore irons

By Paul S. Lane
Research Engineer
Muskegon Piston Ring Co.
Muskegon, Mich.

DURING RECENT YEARS, CONSIDERABLE work has been done on the relation of metal structure to wear resistance, and it is now quite generally accepted that structure, rather than hardness, mainly determines the wear resistance.

In spite of this broadened knowledge, the nature of wear itself yet remains an elusive quality, since it appears that each individual type of installation (having apparently its own particular set of conditions) reacts differently. These uncertainties are further accentuated by the fact that there is no standardized or accepted method for measuring wear resistance. In fact, it has been authoritatively stated that it would be highly undesirable to standardize wear tests, as the apparatus cannot possibly simulate true conditions of all classes of service. In quite the same way no standardized corrosion test has been found broadly acceptable.

Many different types of machines have therefore been used with varying degrees of success. All of them fail, in one respect or another, to duplicate exact operating conditions, yet each of these attempts to measure wear has added a bit more toward our total knowledge of wear characteristics in metals.

In a previous paper entitled "Some Experiences with Wear Testing", presented before the American Foundrymen's Association in May 1937, the present author described some results from a testing machine of the "brake shoe type", wherein a flat specimen is held against a revolving drum by a constant force and without lubricant. A feature of this procedure is that at the start of the test, the unit pressure is extremely high (momentarily at infinity since the specimen makes only line contact with the drum). As wear occurs, and the drum digs into the flat test surface, the actual unit pressures drop according to the rate of wear of each specimen. The halftone on page 316 illustrates the machine.

An arbitrary classification or rating that has been used is as follows: The metal is said to have "excellent" wear resistance if the standard specimen loses less than 18 mg. weight per hour, "good" if its wear is 20 to 24 mg., "fair" if from 26 to 30 mg., and "poor" if the loss is over 30 mg. per hr.

During the past few years, metal in automotive and diesel engine cylinder bores has been studied with this machine. It has involved work with cast iron having a rather wide range in microstructure, brought about in part through differences in the cooling rate and metal thickness.

Gray cast iron is markedly affected by its speed of cooling, and this is in turn largely determined by the section thickness of the casting. This action is illustrated in the table at the head of the next page showing the effect of section on the same ladle of iron poured in different size test bars, molded similarly, the

combined carbon and hardness increasing as section size decreases.

The change in hardness also means a change in other properties such as graphite size, strength of the iron and its wear or abrasion resistance.

Aside from the section effect, structural variations are also influenced by various foundry procedures such as melting and pouring temperatures, molding materials, gating, shakeout practice — all of which may vary even though the analysis may be constant.

Automotive Engines

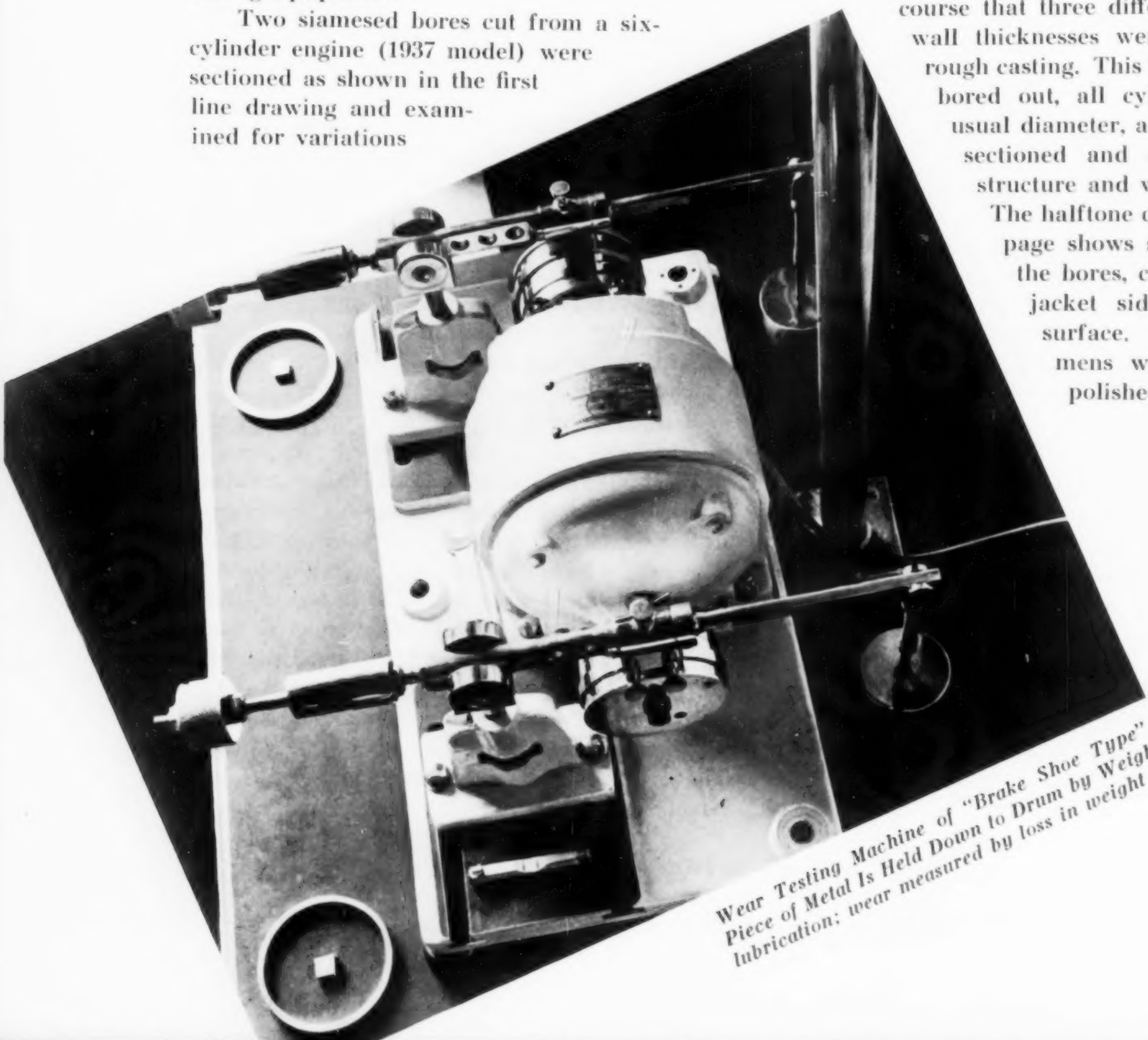
When these points are considered, one readily appreciates the complexity of an engine cylinder casting, having as it does a wide range of section thickness with varied rates of cooling. Consequently specimens were taken from various locations and tested for wear on the machine previously referred to. The balance of this paper will be devoted to these results and also to the various structures found. It is believed that the data will also illustrate the usefulness of some form of wear or abrasion testing equipment.

Two siamesed bores cut from a six-cylinder engine (1937 model) were sectioned as shown in the first line drawing and examined for variations in its hardness, structure and wear. Results are also given in the graph. It will be noted that while the maximum hardness variation is 5.5 points of hardness on the Rockwell B scale (B-88 to B-93.5) the wear varies from 12 to 27 mg. per hr. or better than 2 to 1. Also, it will be seen that considerable variation in wear is found along any one longitudinal section, and that all sections show the highest hardness and lowest wear near the top. In these two bores, the best wearing area is along the 90°-270° line, where, due to the absence of water jacketing, the section is thickest.

Variable Hardness in Test Bars, as Cast

Diameter	Graphitic Carbon	Combined Carbon	Brinell Hardness
2 in.	2.95%	0.45%	160
1.5	2.90	0.50	180
0.75	2.80	0.60	210
0.56	2.65	0.75	260
0.19	2.40	1.00	320

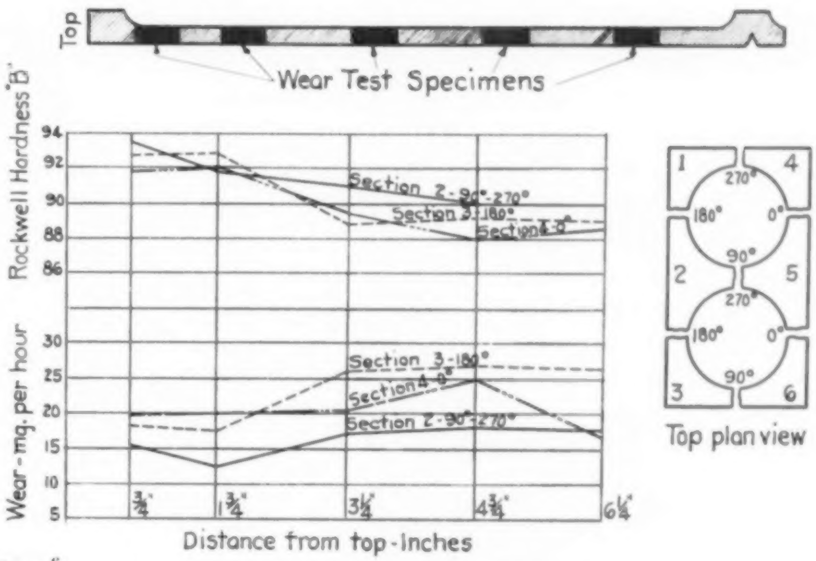
As a result of this preliminary work an entire six-cylinder engine block was cast, using three different size cores, thus giving two bores of each size. This means of course that three different cylinder-wall thicknesses were had in the rough casting. This block was then bored out, all cylinders to the usual diameter, and it was then sectioned and explored for structure and wear variation. The halftone on the opposite page shows six sections of the bores, cut from water jacket side to cylinder surface. All the specimens were mounted, polished and etched



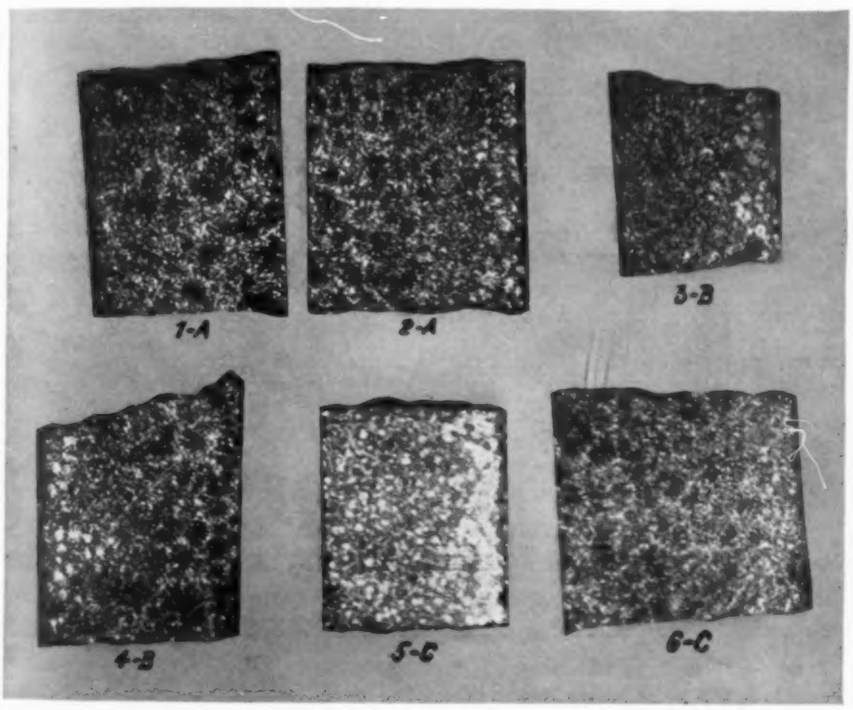
Wear Testing Machine of "Brake Shoe Type" Wherein Flat Piece of Metal Is Held Down to Drum by Weighted Levers. No lubrication; wear measured by loss in weight of flat test piece

as a single specimen, and photographed at five diameters. This low magnification readily illustrates structure variation from section to section as well as across the bore section. The caption gives the chemical analysis, hardness and wear values.

This block, other than the core variation, was cast in normal production. The 5-C section is apparently the "step-child" of the six, showing low hardness, high wear, and an unusual ferrite-graphite structure. There appears no good cause for this except critical cooling conditions. Traces of this same type of structure, mainly superfine graphite and ferrite, are also seen along the water jacket side of some of the other sections, and were very likely on the bore side before machining. This would lead one to suspect that blacking or other material used on the cores might inoculate the metal and cause this undesirable structure.



Twin Bores From a 6-Cylinder Engine Block Show Hardest Metal Near the Top, but This Hardest Metal Wears Most



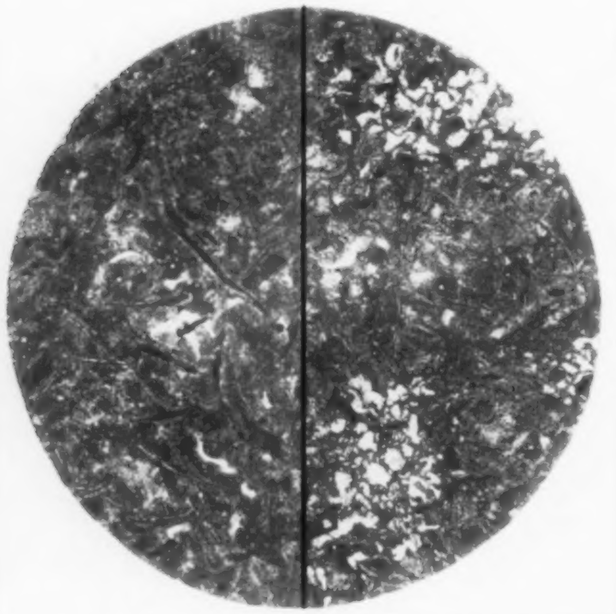
Structure of Cylinder Walls (5 ×) From Block Cast With Small, Medium and Large Cores. Cylinders bored to correct diameter before sectioning. In above samples water jacket side is at right, core side at left. Analysis of iron: 1.80% Si, 0.12% S, 0.25% P, 0.75% Mn, 3.25% C

Sample	Hardness	Wear
Small Cores (Heavy Section)		
1-A	B-88.5	18 mg.
2-A	B-88.9	20
Medium Cores (Medium Section)		
3-B	B-86.4	22
4-B	B-87.5	22
Large Cores (Light Section)		
5-C	B-85.4	46
6-C	B-89.4	22

The author pointed out in previous papers (S.A.E. *Journal*, October 1939 and *Transactions* A.S.M.E., February 1940) the poor wearing qualities of structures of this type. It has also been suspected of having undesirable scuffing tendencies. Dieker and Bancroft have observed its sensitivity to section effects or cooling rate, and have suggested the name "secondary ferrite". Several foreign investigators have also studied structures of a similar nature, and recently Crosby, Parker and Herzig have also offered a metallurgical explanation of its mode of occurrence. Normal ferrite would be expected to be found ordinarily in the heavier section rather than in the thinner, faster cooling section. Here, however, we find ferrite predominating in the 5-C bore section, the lighter "as cast" section.

Further investigation on cylinder blocks indicated that this and equally significant variations were more prevalent than we supposed.

Another siamesed casting contained this undesirable structure over practically all of one of its bores after finishing to the usual diameter, the bore immediately adjoining appearing normal. At five diameters the abnormal or undesirable structure had a dappled gray appearance. The microstructures of the good cylinder and the undesirable one, after polishing, etching, and photographing at 100 diameters, are contrasted in the engraving below.



Microstructure of Cast Iron in Walls of Adjoining Cylinders (100 ×, Etched). Normal structure at left, abnormally fine ferrite and graphite at right

The normal bore, when tested for wear, lost 15.7 mg. per hr. on a sample 1½ in. from the top, and 14.2 mg. 3½ in. from the top. Corresponding samples from the undesirable surface lost 28.0 and 34.7 mg. respectively.

The engine builder with whom this work was carried on was enabled, after considerable experimentation, to improve and largely eliminate this condition. This was accomplished mainly through control of cooling conditions in the casting. Dynamometer and road tests indicated improved uniformity and reduction of wear with the new practice, and thus confirmed the findings and predictions of the laboratory wear test.

The foregoing tests were on one make of engine. However, further investigation indicates that no single type of bore structure is found in engines of different manufacturers. The engraving on page 319 shows bore sections, again at about five diameters, etched, from four automotive engines by four different manufacturers. These illustrate what a wide range exists. One would naturally expect that of the various types found, some must likely be better than others. The caption gives the analyses, hardnesses, and wear values of the four cast iron sections shown.

Diesel Cylinder Castings

Another interesting investigation had to do with two small diesel engines, one having a 3½-in. bore, the other 4½ in. Section thickness of the bore proper was $\frac{3}{16}$ to ⅜ in. for the smaller engine, approximately ¾ in. for the larger one. The smaller engine showed normal wear in service, while the larger bore was giving high wear and scuffing troubles. Data on these castings are given below.

	3½-In. Bore	4½-In. Bore
Silicon	2.10%	1.92%
Sulphur	0.061	0.097
Phosphorus	0.19	0.14
Manganese	0.68	0.69
Total carbon	3.11	3.28
Graphitic carbon	2.55	2.86
Combined carbon	0.56	0.42
Nickel	0.57	Nil
Chromium	0.08	0.10
Molybdenum	0.06	0.31
Average Brinell hardness	185	158
Rockwell range	B-87 to 91	B-80 to 85
Wear value	15.8 mg.	18.6 mg.

The wear value of the larger bore engine indicates satisfactory durability (weight loss) so this value does not correlate with service. However, it shows that the normal ferrite-graphite structure, if accompanied by large graphite flakes, resists wear (due to its toughness) insofar as weight loss in our testing machine is concerned. This very toughness accounts for the scarring and scuffing tendencies of such structures. While this is not always clearly defined, it was noticed that the contact surfaces of these specimens were unusually rough. A similar matrix, if accompanied by fine eutectic graphite which more completely breaks up the continuity of the structure, would show a much higher wear rate under test.

Such undesirable structures are due to incorrect chemical analysis for the section thickness. Thick or heavy sections cool slowly, and may allow time for the structure to reach the so-called "stable equilibrium state" — undesirable combination of ferrite and graphite — instead of the normal pearlitic microstructure.

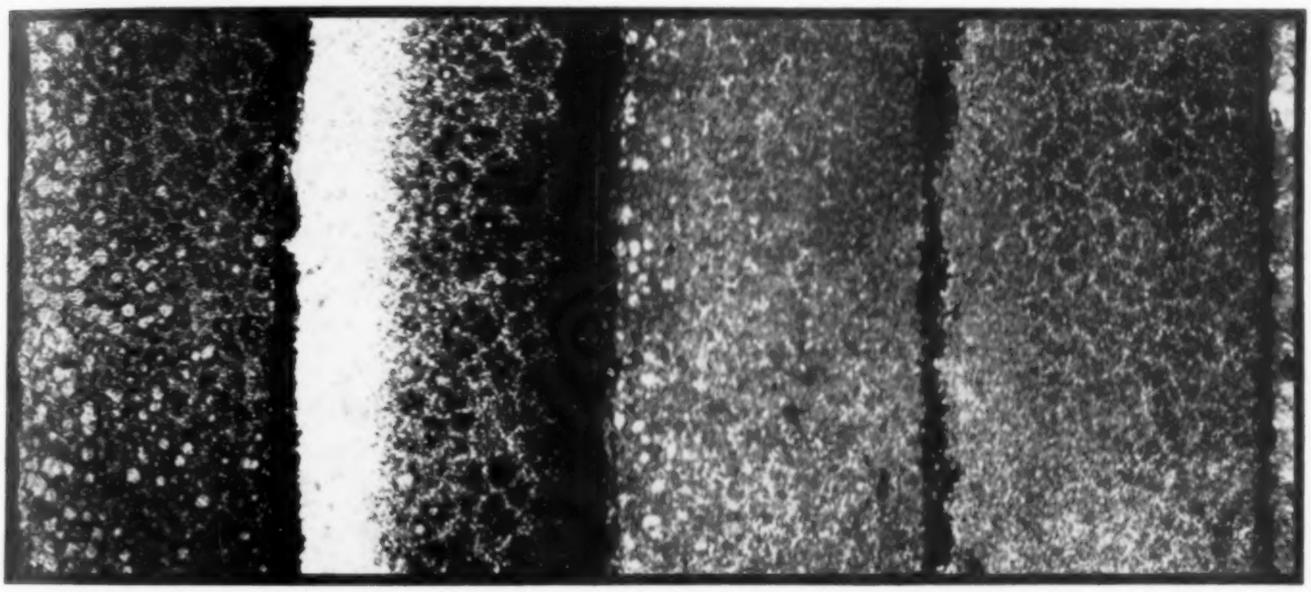
e same iron, with silicon reduced so the cementite would not break down during the wer cooling, would possess a structure similar to that in the $3\frac{1}{2}$-in. bore.

Such conditions are apt to occur where castings of varying types and cooling rates are made under a broad chemical specification. The foundryman should not be held entirely responsible; the fault lies with the engineer or purchasing department who may sometimes fail to appreciate the relation between chemistry and mass effect, and demands that all castings fall within a specified composition. This illustrates the need for close cooperation between the engineering and foundry departments — a matter which is being constantly urged by various technical societies.

Another example of the complications resulting from section thickness and design is the case of a cast iron port section from a two-cycle diesel engine having a bore around 10 in. diameter. The ribs at the port opening have a relatively thin section, which is further exaggerated if the ports enter the cylinder tangentially rather than radially. The tangential design gives a thin tapered section immediately at the bore surface.

Under test, and in service, these engines wore normally at the areas above and below the ports, where metal thickness was approximately $\frac{3}{4}$ in., but excessively along the port ribs, where metal thickness varied from $\frac{1}{16}$ to $\frac{3}{8}$ in. Aside from the metal structure, it is true that more wear would naturally be expected around the port areas for many reasons — the chances of maintaining an oil film are greatly lessened, and the unit loading would be higher. However, the trouble was so pronounced that microscopic and wear tests were instituted. The port areas had fine dendritic graphite and numerous spots of free ferrite, an "abnormal" structure. Its hardness was Rockwell B-90 and the wear loss was 30 to 35 mg. per hr. under test. The full sections were slightly softer and had wear losses from 15 to 23 mg. per hr.

Silicon	2.33%	2.43%	1.70%	2.14%
Total carbon	3.38%	3.17%	3.28%	3.30%
Brinell	165	156	160	172
Wear value	41	30	30	25



Wide Range of Bore Structures and Wear Resistance of Engine Cylinder Walls in Four 1938 Automobiles

As a result of improved foundry practices the situation is much improved. Average of eight samples from as many different cylinders now gives:

	Full Section	Port Areas
Hardness	B-92.8	B-92.3
Weight loss	13.8	23.2

General Discussion

The foregoing data serve to show how design influences the metal structure, which in turn appears to determine the resistance to abrasion or wear. The various structures encountered in engine bores would lead one to believe that further experimentation should

result in improved performance. It is realized that a multi-cylinder block is indeed a complicated casting, and must satisfy many requirements from an engineering and production angle. Already we find many engines with inserted valve seats and guides, and to a lesser extent wet or dry liners. These are necessary because it is difficult or impracticable to obtain satisfactory structure and wear at these various points, as well as because of other considerations of design, performance, and maintenance of the engine.

While cylinder wear alone may not be considered acute at the present moment, it will be agreed that scuffing and scoring of rings and cylinders warrants attention. There is every reason to believe that certain of the structures illustrated are much more prone toward failure from this cause than others. Also, it is believed that some of the apparently mysterious cases of excessive wear or scuffing may, upon further study, be traced to bore structures.

It is believed that the improvement of bore structures will require somewhat different lines of attack in each engine plant, and for this reason no general recommendations are made, nor sweeping conclusions drawn.

Since this subject has received rather limited attention by previous writers, it is hoped that this brief review of existing conditions will encourage further investigation.

Light Alloy Ship Construction

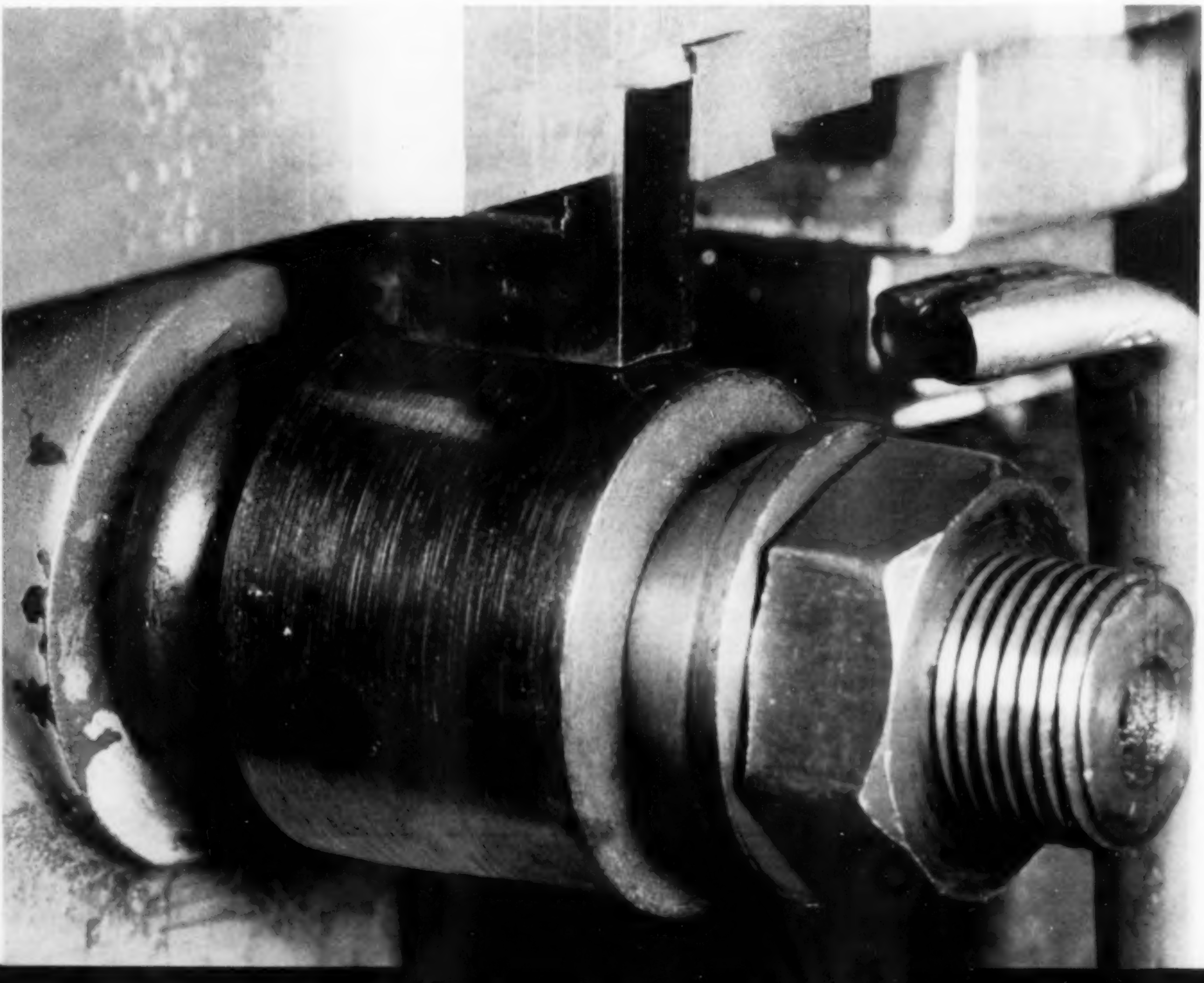
By W. C. Devereux and E. V. Telfer

Abstract of paper before British Institution of Naval Architects, March 31, 1939

ALUMINUM as a shipbuilding material received considerable attention in the 1890 decade, but the lack of strong alloys resistant to sea water corrosion halted its applications until the 1930's. This major difficulty has now been entirely overcome by the aluminum-magnesium-manganese type of alloy, which has shown excellent resistance to corrosion and has produced a first-class structural alloy of strength and corrosion resistance fully equal to that of modern shipbuilding steels. We now propose a generic name ("Navalium") for such alloys, available now in considerable variety and having the guarantee of the whole aluminum industry as suitable for marine use.

In materials of the Navalium class the requisite strength properties are chiefly provided by cold rolling rather than by heat treatment. There are, however, various successful Navaliums strengthened by heat treatment alone; these represent the aluminum-silicon-manganese-magnesium group. Three grades — low, medium, and high tensile — can always be specified with Navalium, despite the inevitable improved tensile properties which will occur in each grade with future progress.

Existing light alloy craft are *(Cont. on p. 350)*



"Wear Test"

Photograph by Prof. Richard Schneidewind, University of Michigan, shown in the 1940 A.S.T.M. Photographic Exhibit

Recommended Electrode Materials

Chart adopted by Resistance Welder Mfr's Asso. for Spot Welding Similar and Dissimilar Metals When Time, Current and Pressure Are Properly Controlled and Conventional Methods and Welders Are Used.

To Weld Similar Metals

To Weld Similar Metals read block under metal to be welded.

	Ferrous								Non-Ferrous								
	Tin-Plated Steel	Terne-Plated Steel	Galvanized Iron, Zinc Plate	Cadmium-Plated Steel	Chrome-Plated Steel	Stainless Steel, 18-8 Type	Scaly Hot Rolled Steel	Cold Rolled Steel; Clean Steel	Aluminum	Aluminum Alloys, Duralumin	Cupro-Nickel	Nickel Silver; Nickel Brass	Nickel	Nickel Alloys, Monel, Nichrome (High Resistance)	Yellow Brass, 25 to 40% Zinc	Phosphor Bronze	Silicon Bronze, (Everdur, Olympic, Duronze, Herculoy)
	B, I I, 3	A, I I, 3	A, I (II) I (II), 3	B, I I, 3	A, II II, 3	A, III (II) III (II)	B, I (II) I (II), 2	A, II II	B, I (II) I (II)	B, I (II) I (II)	A, II II	B, II II	A, II II	A, II II	B, II II	A, II II	A, II II

To Weld Dissimilar Metals

Ferrous Alloys	Stainless Steel, 18-8 Type	Chrome-Plated Steel	Cadmium-Plated Steel	Galvanized Iron	Terne-Plated Steel	Tin-Plated Steel
Cold Rolled Steel; Hot Rolled Steel, Clean	A, II (III) II	A, II II, 3	B, II II, 3	B, I II, 3	A, I (II) II, 3	B, I II, 3
Tin-Plated Steel		B, II I, 3	B, I (II) I, 3	B, I I, 3	B, I (II) I, 3	
Terne-Plated Steel	B, II I, 3	B, II I, 3	B, I (II) I, 3	B, I I, 3		
Galvanized Iron, Zinc Plate	B, II I, 3	B, II I, 3	B, I I, 3			
Cadmium-Plated Steel	B, II I, 3	B, II I, 3				
Chrome-Plated Steel	A, III (II) II, 3					

Non-Ferrous Alloys	Nickel Alloys	Nickel	Phosphor Bronze	Silicon Bronze	Yellow Brass	Nickel Silver	Aluminum
Cupro-Nickel	B, II II		B, II II	B, II II		B, II II	
Silicon Bronze; (Everdur, Olympic, Duronze, Herculoy)			B, II II	A, II II	B, II II		
Nickel Silver	B, II II, 1		B, II II, 1	B, II II			
Nickel Alloys	A, II II	A, II II					
Stainless Steel, 18-8 Type	B, II III (II), 1	B, II II (II)					
Aluminum Alloys, Duralumin							B, I (II) I (II)

Block Interpretation:

Weldability: A-Excellent B-Good	Electrode Against
Electrode Against	Special Information

Special Information:
1. Special conditions required.
2. Good practice recommends cleaning before welding.
3. If plating is heavy, weld strength is questionable.

Note: Electrode materials in circles are second choice. Example: (II)

Names of Commercial Electrodes (Not a part of R.W.M.A. Standard)

Class	Manufacturer: Electroloy	Mallory	S-M-S	Welding Sales	Special Adaptabilities
	Group A; Copper Base Alloys				
I	Grade A	Elkaloy A	Alloy 101	Tuffaloy 88	Coated, plated and scaled metals; aluminum
II	XX TX	Mallory 3 Trodaloy 7	Alloy 103	Tuffaloy 77	Clean Steel; yellow brass
III	TB	Mallory 100 Trodaloy 1	Alloy W5	Tuffaloy 55	Projection, flash and butt welders; stainless steel
	Group B; Copper-Tungsten Alloys				
X	Electroloy 1-W-3	Elkonite 1-W-3	Alloy 1	Tuffaloy 1-W-3	Stainless steel; yellow brass
XI	Electroloy 10-W-3	Elkonite 10-W-3	Alloy 10	Tuffaloy 10-W-3	Inserts and facings; light projection welding
XII	Electroloy 20-W-3	Elkonite 20-W-3	Alloy 20	Tuffaloy 20-W-3	Heavy projection welding; upsetting
XIII	Electroloy 100-W	Elkonite 100-W	Alloy 100-W	Tuffaloy 100-W	Red brass; copper

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THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK, N. Y.

SELECTION OF STEELS

as affected by tensile properties

By Gordon T. Williams
Metallurgist
Deere & Company
Moline, Ill.

A DISCLAIMER SHOULD BE MADE AT THE very start of this series of articles on the general topic of "Selection of Steels for Manufacturing Applications" (articles based on a series of lectures given before the Tri-City Chapter ⊕). I am not going to write about all the factors. No one will know *all* about how to select materials; plenty of men could do a better job than I — but no one has elected to try. So I will discuss, by no means profoundly, those fundamental properties that distinguish steel from other metals — things that make it the most valuable metal to man — and the best way to make use of it for ordinary purposes.

One thing in connection with the selection of steels is that a surprising number of people, consciously or unconsciously, have a hand in it. It is probable that not more than 10% of the readers of this article have a title which means "The Man Who Specifies Steels". However, *every one* of us, technical or non-technical, metallurgical or just plain consumer, helps to specify steel in some way. For example, the man who buys an automobile and breaks a bumper helps to specify steel on the next year's model. The man who heat treats the steel does the best he can but perhaps does a poor job of heat treating, and makes it necessary that a larger factor of safety be put into the steel or the design. The machinist who leaves deep tool marks so that a part breaks too easily may make it seem desirable that the man who specifies turn to a much more expensive grade of steel. The man who makes extravagant claims when selling automobiles, tractors, farm implements, or business machines, makes endless problems for the man who specifies materials.

First let us remind ourselves what steel is. Maybe the simplest practical definition is that it is a rustable magnetic metal, and to my friends in the non-ferrous field, I have but one battlecry, "If you can't pick it up with a magnet, it ain't metal!" A good and less facetious definition is from Bullens' "Steel and Its Heat Treatment": "Steel is an alloy of iron and carbon usefully malleable as cast." This divides it from iron-carbon alloys such as the gray irons which are not forgeable, or from malleable cast iron which is hard iron as cast. It is not entirely accurate because some useful steels would not meet the definition "malleable as cast" — Hadfield's manganese steel for one.

To the iron and carbon in this alloy, malleable as cast, may be accidentally or intentionally added numerous other chemical elements: Manganese, deliberately; phosphorus, sulphur and silicon, both accidentally and deliberately; aluminum, nickel, chromium, molybdenum, tungsten and cobalt deliberately except for residuals that are carried over from one heat to another in remelted scrap. Hydrogen, oxygen and nitrogen should also be mentioned; nitrogen may be added intentionally to the high chromium steels or in certain case-hardening operations and is extremely important. These gases do a lot of things to steel.

but there is very incomplete knowledge of how to control them; much research work is now being done on this.

There are some things in steel that are not steel — not metal — such as sulphide, oxide and phosphide inclusions. Sometimes these are deliberately added; for instance, aluminum is deliberately added to control grain size by means of its oxide which is inevitably produced.

Steel is certainly the most useful metal to man. BULLENS goes on to say "Steel combines strength, workability and cheapness to a degree unparalleled in any other material of construction." Every year the civilized world (so called) makes a hundred million tons of it or more.

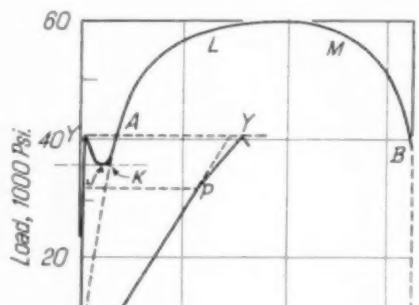


Fig. 1 — Stress-Strain Curve for Mild Steel, Showing Portion Below Yield Point With Magnified Horizontal Scale so Proportional Limit P Can Be Located

Now to get down to the business of selection of metal. In stationary parts with plenty of foundation, weight is not much of a factor, but in moving parts the weights are limited by economical moving costs. HENRY FORD discovered this early in his career; the Model T of pleasant memory revolutionized manufacture (and present day living) in many ways, not least of which was the wholesale use of heat treated alloy steel whereby he was able to cut half a ton of weight off the previous horseless carriages.

So how about the *weight* of our metals?

The accompanying table is from HORACE C. KNERR's article in METAL PROGRESS for January 1937 entitled "Heat Treated Alloy Steel — the Lightest Material of Construction". From it, it is at once apparent that light weight is only important if the light-weight metal is also strong.

Strength-Weight Factors H. C. Knerr

MATERIAL	TENSILE STRENGTH PSI.	AVERAGE SPECIFIC GRAVITY	STRENGTH-WEIGHT RATIO
Aluminum, commercial, 2S	13,000	2.71	4.8
Iron, ingot	40,000	7.87	5.1
Steel, cold rolled	60,000	7.84	7.6
Aluminum, cold rolled, 2S-H	24,000	2.71	8.9
Steel, S.A.E. low alloy, low carbon	160,000	7.85	20.4
Aluminum alloy, 17S-T (duralumin)	58,000	2.79	20.8
Spruce for aircraft	10,000	0.435	23.0
Aluminum alloy, C17S-T	65,000	2.8	23.2
Steel, S.A.E. medium alloy, medium carbon, heat treated	190,000	7.85	24.2
Aluminum alloy, 24S-RT	68,000	2.77	24.5
Magnesium alloy, AM58S	46,000	1.85	24.9
Steel, 18-8 stainless, heavily cold rolled	200,000	7.93	25.2
Steel, high alloy, high carbon, heat treated	250,000	7.85	31.8
Steel, piano wire, cold drawn very fine	400,000	7.84	51.0

Hence the strength-weight ratio, dear to all writers and talkers about aircraft construction, which is the quotient of dividing the expected tensile strength by the average specific gravity of the material.

Commercial aluminum is a light metal and aluminum is often spoken of as being stronger than steel — of course, that means common steel like sheet steel. But this is not true, for commercial aluminum has a strength-weight ratio of 4.8 and ingot iron (the softest commercial sheet) has a strength-weight ratio of 5.1, and when moderately cold rolled or drawn it is 7.6 A heat treated alloy steel with a lot of strength has a strength-weight ratio of 20.4, right on the heels of 17S-T, typical duralumin, as used in aircraft. Spruce (wood) incidentally shows 23.0 Another heat treated aluminum alloy is listed (24S-RT) that shows 24.5. Magnesium alloy has comparatively little strength but, by virtue of very low specific gravity, picks up a strength-weight ratio of 24.9. Cold-rolled stainless sheet, with tensile strength around 200,000 psi., has a strength-weight ratio of 25.2, exceeded only by high carbon steel piano wire, cold drawn, with an unapproached strength-weight ratio of 51.

This table indicates perhaps why we think so much of steel, why we find it so useful, but it does not normally have most useful properties as received from the steel mill. Ordinarily the best properties of the best steels are developed by heat treatment. So we will confine discussion in this series of articles to engineering steels — in a broad way, the S.A.E. steels so widely used and specified.

You will have noted that we have just spoken of "tensile strength", and since it — next to hardness — is the most commonly used mechanical property, a discussion of the tensile test is in order. Despite the scientist's conclusion that it shows most frequently the *shear* strength rather than tensile strength, and the inspector's feeling that it is primarily useful to indicate uniformity in general quality of the metal, the purchaser inserts tensile

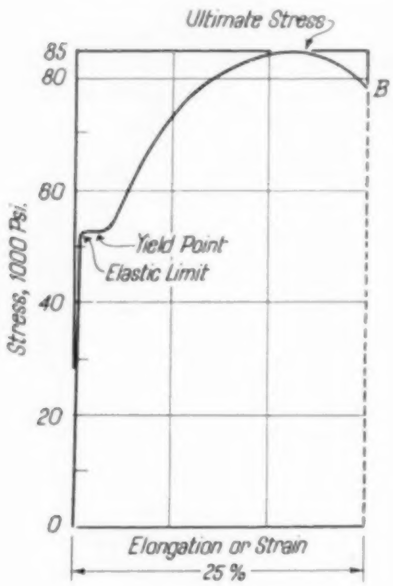
properties in nearly all his specifications and the art and science of machine design is based on figures from the tensile test.

Opposite is a typical stress-strain diagram in tension. "Stress" means load per unit area, and in America is expressed as pounds per square inch (abbreviated to psi.). "Strain" means unit elongation, measured in inches per inch by dividing total change by the original gage length. A specimen of metal 0.505 in. diameter by 2 in. gage length, with enlarged ends of any sort, is put into a stretching machine, and a pair of dividers ("extensometers") clamped on to show us the stretch as the load is applied. We add load at intervals and measure the length between gage points, and plot the load vertically and the elongation horizontally. You will find ordinarily that the curve for mild steel will go up as a straight line nearly vertically to a fairly high load. That means, of course, that the steel is carrying considerable load without stretching very much. Suddenly we arrive at a load which will cause quick and rapid stretch, so rapid, in fact, that the weigh beam that measures the load drops, as though the load were in fact reduced. This drop of the beam of the testing machine is plotted as a little jog on the curve at *YJA*. Continue to add load to the specimen; the curve mounts, although stretch is now rapid, to points plotted as *L* and *M* and by and by it starts to require less load, and then breaks at a load plotted at *B*.

What are the characteristics of this particular curve? This unit load at the high point between *L* and *M* is called the tensile strength, or ultimate strength; the unit load at the point *Y* where the beam suddenly drops is called the yield point. The latter is a very easy point to find on mild steels; these show a definitely marked yield point. It is not a particularly useful property to machine designers — although structural and marine engineers who use soft steels pay a good deal of attention to it — for it can't be found at all on many heat treated and cold-drawn steels, nor on non-ferrous alloys.

While applying the load, we find that by dividing the figure for load into the figure for stretch that the deformation up to a certain point is strictly proportional to the load; we say that the material is deforming in an elastic manner. We are, of course, confusing the meaning of words here, for "elastic" action more precisely means that the piece returns to its original size and shape after release of load. There is nothing in "proportionality of stretch to load" that insures elastic action, although it usually so happens. The proportional or straight-line action continues until we come to point *P* which is known as the proportional limit (not limit of elastic behavior or "elastic limit" — the elastic limit, where permanent set due to plastic flow occurs, may be somewhat higher). Generally speaking, once we have passed some point above *P*, the material starts to deform plastically — begins to stretch permanently, to elongate and reduce in area. Up to the point of maximum stress between *L* and *M*, the elongation is entirely general — uniform all over the gage length. The reduction of area is also uniform; the specimen has been made smaller in diameter, and gets longer, but at point *M* the material starts to elongate locally, to reduce in area rapidly at a certain region, and, as known long before modern slang, it begins to "neck". Everybody knows what a typical specimen fracture looks like — it has high local elongation just around point where

Row of Tensile Test Pieces of Steel, From Soft to Hard, Showing Range in Ductility as Indicated by "Neck". Test piece on right is hardened, high carbon steel; it broke outside the gage marks with practically no elongation or contraction (later flattened for hardness tests). Cartridge brass elongated uniformly about 50% before necking started and test stopped



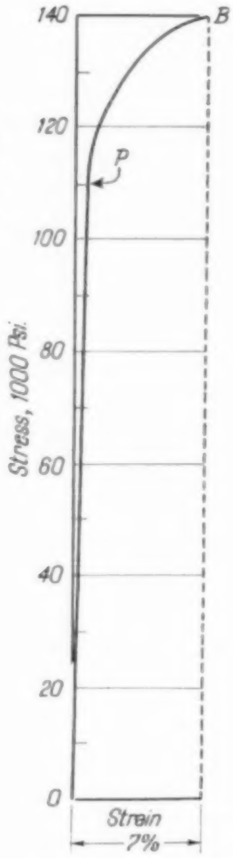


Fig. 3 — Stress-Strain Curves for Hot-Rolled Steels, Not Heat Treated, (Left) Having Medium Carbon and (Right) High Carbon. The latter has no well-defined "yield point"

high reduction of area takes place; elsewhere the elongation and reduction of area are pretty much as they were at the time the specimen was carrying the maximum stress *L-M*.

The diagram above shows how the shape of the stress-strain curve may vary with different steels. A typical medium carbon steel will probably show drop of beam in test, and as before this would be reported as yield point. Then we go on to an ultimate strength. In high carbon or heat treated steel, the yield point is not ordinarily shown by a drop of the beam; specimens begin to deform permanently at about point *P*, the proportional limit. Ordinarily this point must be determined from a stress-strain curve, either drawn autographically by the testing equipment or plotted from readings of load and corresponding stretch.

One term that will see a lot of use is "yield strength" or "yield stress". This term is designed to get around the confusion in such terms as "elastic limit", "proportional limit", and "proof load". "Proof load", in its general sense, means the load that the specimen or the completed structure must carry without distress, and may be a condition of acceptance in a contract. To a testing engineer the "proof load" and the "yield strength" ordinarily mean that load on a tensile test specimen which gives a definite elongation, usually 0.2%, and this usually is just over into the plastic range. The figure 0.2% is selected because it is the smallest extension readily detectable by the doubling of a line scribed by dividers before and after loading the 2-in. gage length.

Don't forget one thing — the material is actually as strong as the maximum load shows — even stronger, for the stress plotted on the diagram is figured on the original cross-section of the piece, whereas the sample at that time has contracted crosswise somewhat, in keeping with the elongation that has occurred. How has it got that strong? By work hardening. We will see in a later discussion of cold-drawn steels what can be done in the way of work hardening, but here is an example of substantial work hardening. Though smaller in diameter, the specimen carries more load than before.

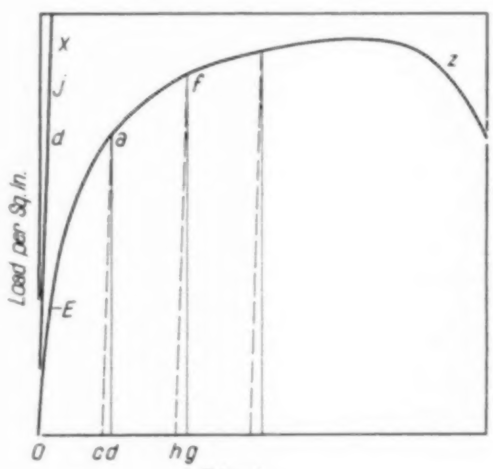


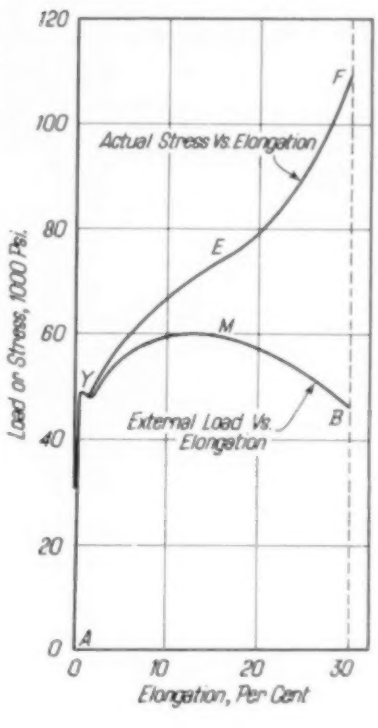
Fig. 4 — Steel Strained Beyond Elastic Limit E Acquires Permanent Set, as Shown at O-c, but Simultaneously Has Elastic Limit Raised Approximately to a

The sketch at the left shows this work hardening characteristic of a heat treated alloy steel. While there is no definite yield point we get elastic deformation at first and some place up about point *E* — call it yield strength — it begins to deform plastically. If the load is released at any time before the elastic limit is reached, the piece returns to its original dimensions, and reloaded the curve would start off again from *O*. Continue the loading to load *a*, corresponding to an elongation of *o-b*, however, and we find it will not return to its original dimensions; it contracts only a distance *d-c*, having acquired a permanent set of *O-c*. Put on load again and the stress-strain curve follows substantially the straight line *c-a*, appearing to act "elastically" up to point *a*.

Such "cold work" of overstrain has actually raised the elastic limit of the steel from load *E* to load *a* — quite a remarkable fact!

The last stress-strain curve (Fig. 5) shows another interesting thing. Curve *A-Y-M-B* is a typical tensile test of a bar of metal. Remember

…5 — *If the Load on a Specimen Is Figured on Its Actual Cross-Sectional Area, the True Stress Is Shown to Increase Steadily up to Ultimate Fracture*



At the time this bar breaks, it is much smaller in diameter than before, so if a recalculation based on actual diameter at all times is made, we find the stress-strain curve of *A-Y-E-F*; evidently the metal has continued to strengthen per unit of area up to the last. Elongation is stretch, stretch as measured between a couple of gage points chosen as reference, and if a lot of it is concentrated in a neck, the *average* elongation will be a smaller figure for a long gage length than for a short gage length. Round test bars are usually tested with 2 in. gage length; test bars cut from plates are tested with 8 in. gage length. For the same material in the same condition the elongation figure for plate is much less than for a bar specimen. The figure for reduction of area is independent of gage length; once the specimen begins to neck down, it will reduce to the same final diameter whether the specimen is long or short.

We must pass on to consider the nature of some other of the useful properties of steel allied to the tensile properties. The *torsion test* is simply a twist rather than a pull. It is ordinarily thought of as determining the shear properties. It is infrequently performed; ordinarily we are safe in assuming that the yield in shear and the ultimate torsional strength is about 60% of the yield and the tensile strength respectively. Other types of shear test have special applications — shear tests for rivets and bolts are very important and would ordinarily be tested in a fixture that approximates the action of scissors.

In the *bend test* a piece of steel, in original shape or machined down, is bent around a pin of certain diameter in a vise or slow acting press. The number of degrees it must bend before cracking is often specified. This is a very useful test because it requires the outer fibers to stretch a lot, and is favored by welding engineers as a searching test for quality of joints. It has been said that it takes about 35% reduction of area in a tensile specimen cut from steel castings to give 180° cold bend in the typical cold bend test. The amount of elongation at the outside of the bend can be figured from the curvature, either by tracing the curve on paper or by using a three-point straddle gage.

Always bear in mind that the properties of hot-worked steel vary with the direction of rolling or forging; wrought iron has a grain or fiber similar to wood because the metal has strings of slag worked out under the hammer. Wrought steel also has traces of this fiber, even though it is relatively free of slag particles.

Such directional properties are indicated in Fig. 6, wherein the investigator took a plate of first class

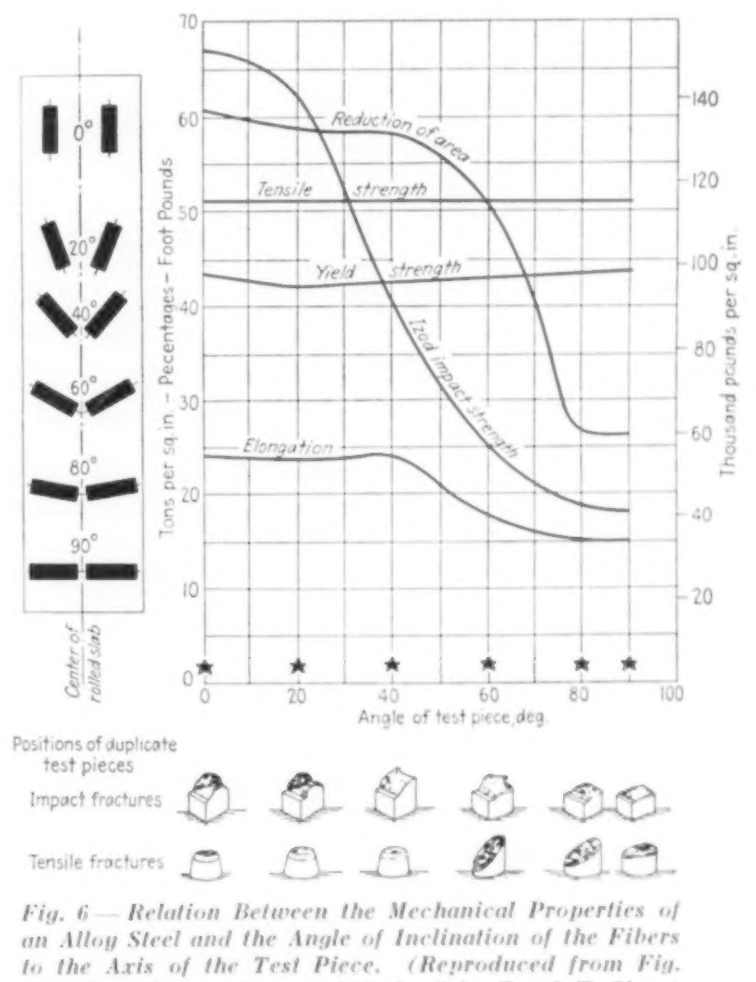


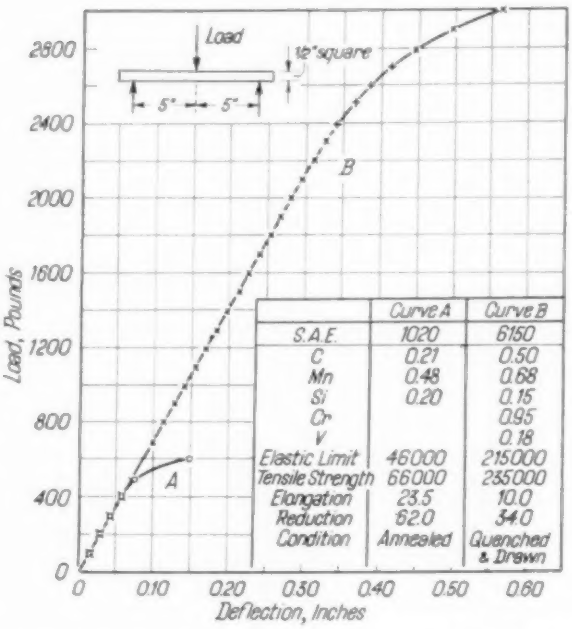
Fig. 6 — Relation Between the Mechanical Properties of an Alloy Steel and the Angle of Inclination of the Fibers to the Axis of the Test Piece. (Reproduced from Fig. 18, "The Alloys of Iron and Carbon" by Frank T. Sisco)

alloy steel and made test specimens with, across and at angles to the direction of rolling. Notice as the angle is changed, the angle with which we cut the "fibers" or "grain", the tensile strength is about constant, the yield strength varies but little, but the elongation decreases quite sharply from 24 to 15%, reduction of area suffers even more and loses more than half its value. Impact strength is also badly down: 67 ft-lb. down to 18.

The very things that make hot-worked steel have this fiber or directional properties may also be important factors in making castings weak over all, but not necessarily so. Ordinary castings will have no such directional properties, while forgings will have them very promiscuously depending on the way the metal is drawn or upset, but we can take advantage of these properties, as in making forged ring gear blanks. By proper work in the upsetting dies we make the fiber go in the direction where the maximum properties are required, and get a minimum change in shape after heat treating (for fiber has a pronounced effect on warpage). For things such as shafts with heavy spline or keyways, the amount of fibering in the steel may be an important factor; if fiber is very marked, it results in planes of weakness.

Heavy guns on firing are stressed in a way that would make a gun drilled out of a solid bar a very poor gun because all stresses are radial bursting stresses. Therefore gun tubes are hollow forged, between top and bottom bed of the press and an interior mandrel, so that fiber is in a more satisfactory direction.

Stiffness. High strength alloy steels and low strength carbon steels do not differ in the amount of deflection they suffer under a given load, as long as neither is overloaded beyond the yield point. *It is impossible to stiffen a piece of steel by alloying or by heat treatment.* The modulus of elasticity, so called, remains unchanged. The modulus of elasticity is simply the relationship between amount of stress and amount of strain within the elastic limit.



	Curve A	Curve B
S.A.E.	1020	6150
C	0.21	0.50
Mn	0.48	0.68
Si	0.20	0.15
Cr		0.95
V		0.18
Elastic Limit	46000	215000
Tensile Strength	66000	235000
Elongation	23.5	10.0
Reduction	62.0	34.0
Condition	Annealed	Quenched & Drawn

Fig. 7 — Load-Deflection Curve for Bend Tests on Two Steels at Extreme Conditions of Softness and Strength; at All Loads Within the Elastic Limit of Both, Their Stiffness Is Identical

Another way of saying it is that the straight early portion of the stress-strain curves has the same slope for all steels, as long as the curves are plotted to the same scale. Some straight portions may be much longer than others, but the slope will be practically identical. This is shown in Fig. 7 for two different steels (they are bent transversely, but the curves are quite similar to tensile curves). Curve A is for a piece of S.A.E. 1020 annealed, about as soft as ordinarily encountered. Notice that the line is right on top of line B for S.A.E. 6150, quenched and drawn and having five times as high an elastic limit and being $3\frac{1}{2}$ times as strong. So far as the S.A.E. 1020 went *elastically*, the curves coincided. The 1020 started to bend permanently at a load of 400 lb., however, while the 6150 carried about 2300 lb. before it "set".

Relation to Design

Most discussions of the tensile test I have heard stop right here, but — again because no one else has elected to try it — I will add some remarks about what the designer does with the test figures after he gets them.

I want to emphasize one thing — I am no designer nor mechanical engineer; such ideas as I have on this subject have been got from contacts with designers and mechanical engineers. Over a period of years, I have learned some of their characteristics and they may have learned too much of metallurgists'.

Let us start off as is customary with a poem, this one by Ken Lane of Lynn, Mass.

The designer bent across his board,
Wonderful things in his head were stored.
And he said as he rubbed his throbbing bean,
"How can I make this thing tough to machine?
If this part here were only straight
I'm sure the thing would work first rate.
But 'twould be so easy to turn and bore
It never would make the machinists sore.
I better put in a right angle there

Then watch those babies tear their hair.
Now I'll put the holes that hold the cap
Way down in here where they're hard to tap.
Now this piece won't work, I'll bet a buck,
For it can't be held in a shoe or chuck.
It can't be drilled or it can't be ground
In fact, the design is exceedingly sound."
He looked again and cried — "At last —
Success is mine, it can't even be cast!"

That gentle dig at designers may be interpreted to mean that most all design is largely empirical — rule of thumb — "Do it better next time!" There have been wonderful mathematical analyses made of stresses in automotive gears and a lot of other parts. When all is done, the man who designs it says, "And now let's make one and try it." There are so many variables in manufacture and use — the man who abuses his automobile, the man who does a poor job of heat treatment, a bad job of machining — that the required factor of safety (or "factor of ignorance") cannot be predicted in advance.

Any intelligent design is predicated on having certain permissible percentage of failures. All engineering design is a compromise. Your automobile, regardless of what kind of car, is not as well built as it can be — it is as well built as they can afford to build it. There was the "hell-for-stout" designer who made a watch so strong that a horse could step on it.

As far as percentage of failures goes, or minimum expected life, turn to a story of how G. L. Rothrock devised a better transmission for Cadillac and LaSalle cars, as told to the American Gear Manufacturers' Association. When the study began the minimum test life permissible in dynamometer test was 2.6 hr. in low gear at full load. At the end of the study a transmission had been devised weighing only half as much but having 10.7 hr. minimum life in low gear. If the transmission stands that, little trouble can be expected in normal surface.

The same principle applies to a lot of other well-designed parts; a certain percentage of failures is permissible and expected. When engineers begin to get reports around the country that parts are failing, they start totaling them up: "On that job, we sold so many thousands — distributed around the country like this. More failed in Alabama — just a certain part. What are the particular reasons? Maybe something in the air." Or a tractor part is breaking in the state of Washington, where they do a lot of logging, very tough on a tractor. We must think of all those things, and prepare for them if possible, or sleuth out the causes and correct them immediately.

It is not always proper to make a change in the steel. There are limitations in purchasing, especially in this year of 1941. Can we get this steel in the quantities and deliveries we want? Can we machine it? Have we got the equipment and facilities to heat treat? How about cost? How well does our competitor do?

Coming to a specific case, take the very simple clevis shown in Fig. 8, and think of stresses involved. Suppose this is a clevis joining two parts; it carries tensile load at F and F. Diameter d is a limiting area; will that fail in tension or will the yoke fail in tension where it is weakened by the hole for the pin? The pin

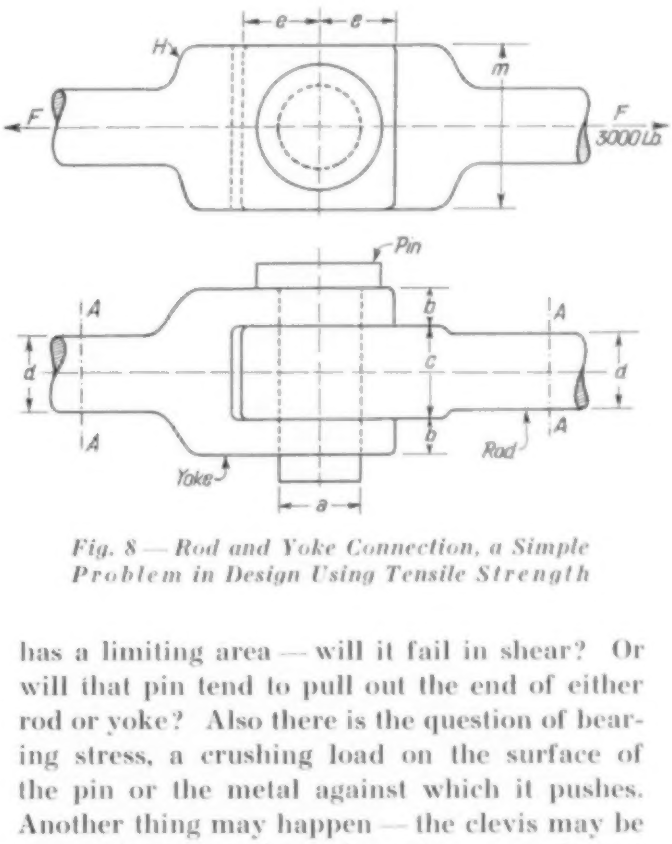


Fig. 8 — Rod and Yoke Connection, a Simple Problem in Design Using Tensile Strength

has a limiting area — will it fail in shear? Or will that pin tend to pull out the end of either rod or yoke? Also there is the question of bearing stress, a crushing load on the surface of the pin or the metal against which it pushes. Another thing may happen — the clevis may be supporting something banging around, and after a few hundred thousand loadings, something may give way. We must therefore think of dynamic properties, of fatigue.

We will have more to say about this matter later, but the designer, given the tensile strength of his material, is able to work out a very satisfactory design for clevis by the principles of mechanics, after certain simplifying assumptions are made. Some pretty complex matters at region H in the yoke are solved by putting in plenty of metal. Later we will find instances where more metal actually weakens the part.

AN EXPOSURE METER

for photomicrography

By H. S. Jerabek
University of Minnesota
and W. W. Wolf
Tennessee Valley Authority
Wilson Dam, Alabama

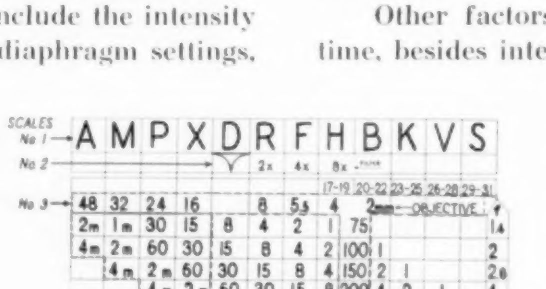
There exists a need for an accurate exposure meter for use in photomicrography, particularly where a series of exposures must be made before any of the films or plates are developed, or where unusual conditions are encountered. This paper deals with the adaptation of an exposure meter popular with amateur photographers to micrographic work.

Several methods of estimating exposure time have been proposed, most of them too cumbersome to find wide application. The system of calculations outlined in the Eastman Kodak Co.'s booklet "Photomicrography" is probably the most useful of these, but it can be simplified and improved by using a device to measure the combined effect of several of the variables involved. These include the intensity of the light source, the iris diaphragm settings, and the reflective power of the specimen. Furthermore, if the calculator chart attached to the exposure meter can be adapted to make the necessary computations, additional simplification can be achieved.

Of the various types of photographic exposure meters commercially available only those which are capable of measuring extremely low intensities of illumination can be used for photomicrography. Most photoelectric meters are not sufficiently sensitive, but the extinction type of meter has been found to be adequate.

The engraving on page 331 shows a popular and inexpensive model of extinction type meter, the "Instoscope", photographed after we had rearranged it for photomicrographic use. The intensity of the light reaching the ocular of the microscope is measured by holding the meter (by an adapter) in the position normally occupied by the eyepiece. Such an adapter can be made of darkened cardboard or metal tubing. The light intensity is considered to be equal to the faintest letter visible on the step scale in the meter.

Other factors which govern the exposure time, besides intensity of illumination, are film speed, filter factor, numerical aperture of the objective, and magnification. It is apparent that the scales on the calculator chart can be adapted to the computation of the combined effect of all these factors, and the attached diagram gives an expanded Instoscope scale with the modifications recommended, of correct size to mount on the barrel.



Modified Scales for Exposure Meter (Changed or Added Numbers in Dotted Areas)

Extinction Type Exposure Meter — the "Instoscope" — Modified for Use in Microscopy (Somewhat Enlarged)

For light intensity values, Scale No. 1 shown in both the diagram and the photograph, is used without alteration. Scale No. 2 is used for the combined effect of film speed, filter factor, and model of microscope. Each combination of these is assigned a number; the factor 2X has been found to be correct for a Bausch & Lomb Model ILS microscope with a carbon arc lamp when using Eastman Kodak commercial ortho film and a light yellow (minus red) filter. 2X is also correct for the Leitz MM microscope with the Leitz liquid green filter, and 4X for the large Zeiss metallographic microscope using Homal oculars and Wratten K2 filter. Since various operators do not all prefer the same average density in their negatives, the factors given here should be checked by experiment and modified when necessary to suit specific needs or individual preferences.

Exposure time varies directly as the square of the magnification; therefore, the *f* value (aperture) scale on the calculator chart can be used for this variable if each *f* value is multiplied by a factor such as 50 or 100. The vertical scale of magnifications in Table I (scale No. 4 in the diagram) was prepared by using a value of 50 for this constant. This scale was extended below the regular Instoscope scale to cover magnifications of 1500 and 2000 diameters. Other figures added to the regular scale are shown within the dotted lines in the drawing, but it has been drawn to scale so that it may be cut out and pasted over a new meter to adapt it for photomicrography without interfering with its use for ordinary photography.

The illuminating power of various objectives varies as the square of their respective working numerical apertures. It was found by experiment that this variation in illuminating power is not taken care of by the extinction meter reading, although the meter does make adequate compensation for moderate changes in the settings of the iris diaphragms. An accompanying table therefore is presented to give the average numerical aperture values for objectives of various focal lengths and also a factor for the illuminating power of each, calculated on the basis of a working aperture equal to two-thirds of the numerical aperture. The correct exposure time varies approximately in proportion to the "objective factors" listed in this table. For convenience in using the Instoscope calculator, Scale No. 3 is added which lists the various objectives by focal length. (This scale covers the Scheiner film-speed scale on the instrument as purchased.) The last

Illuminating Power of Objectives

Objective Equivalent Focus (Mm.)	Average Rated N.A. (Numerical Aperture)	Average Working Aperture; 2/3 N.A.	Illuminating Power Factor★	Approx. Objective Factor; 2-mm. Lens=1	Spacing On Scale No. 3
2 or 3 (oil)	1.30	0.866	1.3	1	0
4	0.90	0.60	2.8	2	1
5.5	0.65	0.43	5.4	4	2
8	0.50	0.333	9.1	8	3
16	0.25	0.166	44	32	5
24	0.18	0.12	70	64	6
32	0.12	0.08	156	128	7
48	0.08	0.053	350	256	8

★Illuminating Power Factor = 1 ÷ (Average Working Aperture)^2

column in the table gives the spacing of the various objectives on this scale, and their positions on the calculator chart are also shown in the engravings. The position of the 2-mm. lens on this scale coincides with the value 20-22 on the Scheiner film-speed scale.

How the Meter Is Used

After the microscope has been focused, the field selected for the micrograph, and the iris diaphragms adjusted, the visual eyepiece is replaced by the exposure meter. A reading is taken for the light intensity with the color filter in place. The same length of time should always be allowed for the operator's eye to become adjusted to the dim light before the reading is made. (Approximately 15 sec. will prove satisfactory for most persons.) The faintest letter that can be read on the step scale is used as the light intensity value in computing the exposure by means of the calculator chart.

Let us assume that an exposure is to be made at 500 diameters, using a 4-mm. objective, the light intensity value is H, and the filter factor 2X (Bausch & Lomb microscope model ILS, E. K. commercial ortho film, light yellow filter). The first step is to revolve the movable part of the calculator chart carrying Scales No. 1 and No. 2, so that the number 2X coincides with 4 mm. on the objective Scale No. 3. The correct exposure time, in seconds, is now found in the vertical column below the then position of H (on Scale No. 1) and on the same horizontal row in which the magnification 500 occurs on Scale No. 4. The proper exposure time is thus found to be 15 sec.

Exposures calculated in this manner will give rather fully exposed negatives. If the operator prefers negatives of lower density the "filter factor" on Scale No. 2 should be reduced. This may be particularly desirable when working with oil immersion lenses where images of rather low contrast are often obtained and where very full development of the negative is necessary to preserve the contrast.

The use of conical illumination requires some adjustment in the calibration of the exposure meter. In general, the exposure time should be increased by 50 to 100% when opaque center stops are used.

The system described here has been in use for over a year and has given excellent results, even in the hands of inexperienced microscopists.

Creep of Molybdenum Steel

By S. H. Weaver

Abstract of "Relation of Grain Size to Creep Strength of Carbon-Molybdenum Steel" in General Electric Review, *September 1940, page* 357

A STATISTICAL ANALYSIS of 32 long-time creep tests of steels which had in common the specified chemical composition of the steel (S.A.E. chromium-nickel-molybdenum steel 4330) and a creep temperature of 840° F. was presented in an article before the A.S.T.M. in 1938. Eighteen of these steels had a uniform microstructure with the carbides in a sorbitic form. When the creep strength was correlated with the size of the structural grain existing in the steel during the creep test, a curve showed an optimum grain size for the maximum creep strength. A grain size larger or smaller than the optimum value gave a decreased creep strength.

The "grain size" considered is not stated in terms of the crystal of the crystallographer, which is bounded only by a change in orientation of the atomic lattice, nor in terms of the austenitic grain of the metallurgist, which in the pearlitic steels exists only above the transformation temperature, but is the effective grain measured in terms of the size of the grains of ferrite, patches of pearlite or Widmanstätten areas, whichever predominates. These different areas or structural grains seem to determine the physical strength of the steel at elevated temperature, and the structure is revealed in the microstructure of the finished product.

This relationship between grain size and creep has been checked by several lines of investigation, the first of which was to determine whether steel at creep temperatures above the presumable lowest temperature of recrystallization had a maximum creep strength obtained by a corresponding optimum size of the structural grain when there was no appreciable difference in the microstructure in each grain; or whether the creep strength merely increases with the grain size until influenced by a changed structure within the grain.

This preliminary investigation involved 32 creep tests of about 2600 hr. each on four alloy steels with eight heat treatments each.

A uniform microstructure was assured by giving to each bar a diffusion treatment to eliminate segregations of ferritic banding. The permanency of each diffusion treatment was then established by re-annealing the samples at 1600° F. for 5 hr. and examining the microstructure after either air

(Continued on page 346)

CORRESPONDENCE

& foreign letters

Diversity of Welding Codes

Cleveland, Ohio

To the Editor of METAL PROGRESS:

In view of the fact that my name was mentioned in the last issue of METAL PROGRESS, I feel called upon to clarify the statements attributed to me in the article by JAMES L. AVIS entitled "Remarks on Welding, as It Is Done".

Inference which might be drawn is that I was opposed to codes, qualifications, tests, etc. This is contrary to the facts. I am not opposed to all codes, regulations, qualifications, tests, etc., but I am opposed to:

1. The fact that many codes are unduly restrictive.

2. The fact that many codes overlap and have overlapping authority.

3. The fact that things which are permitted in one code are not permitted in other codes, even though the objects welded are frequently for similar purpose and subject to similar service requirements.

4. The fact that one code or authority will not recognize the qualification or certification of a welder when he is qualified or certified under another code or authority, even though the work he is required to do is quite similar in character and quality.

5. The fact that one code or authority will not recognize the qualification or approval of an electrode approved by another code or authority, even though the electrode may be used for a similar purpose or similar service requirement.

If the above facts to which I am opposed could and would be corrected, a great service would be performed for the users of welding, as well as the manufacturers of welding equipment and electrodes. They would lessen the cost of welding to a very considerable extent and thus make this splendid tool of humanity of far wider value and utility.

Not only do we need uniform, simplified codes and qualification tests, but we need their adoption by all the various societies, authorities and governing bodies including federal, state and city governments.

A. F. DAVIS
Vice-President
The Lincoln Electric Company

Powdered Iron, a Byproduct of Bauxite Purification

Turin, Italy

To the Editor of METAL PROGRESS:

The problems concerning the use of calcined pyrites and sulphurous iron ores for smelting into iron and steel have been extensively investigated during the last few years. Interesting practical solutions have been based on different principles; some have already been satisfactorily installed on a large industrial scale, especially in countries like Italy where good iron ore is comparatively scarce, and large quantities of calcined pyrites and sulphurous ores are available.

The processes so far applied on a large scale may be divided in two classes: The first includes those wherein calcined pyrites are smelted in arc furnaces in the presence of suitable fluxes and under special conditions, in order to desulphurize practically completely to a good quality pig iron. These have been largely adopted in Italy, and are economical only on the condition that quantities of cheap power are available.

The second group of processes is based on the production of a desulphurized sinter, suit-

able for further economical reduction either in ordinary blast furnaces, in rotating kilns using reducing gas, or in electric furnaces. These have also been used in Italy, and are commercial when the ore is not too high in gangue, requiring the formation of unreasonable quantities of slag.

Recently various experiments have been made with a third treatment, based on the transformation of the different iron oxides into magnetite, Fe_3O_4, and the magnetic separation of this from the gangue. Early attempts to perform the "magnetizing roast" failed because of incomplete transformation of the different oxides into magnetic oxide; a new modification, patented by the Italian engineer De Vecchis, and tested on industrial scale at Rouen, France, has given excellent results in every respect. He depends upon the fact that the only iron oxide stable at temperatures in the neighborhood of 1500° F. in presence of air at the normal atmospheric pressure is Fe_3O_4; under those conditions a magnetite should be obtained practically free from any other iron oxide and having physical properties favoring its magnetic concentration in a pure condition up to 96 or 97% pure. Thus the drawbacks of all three groups of processes (namely, the high consumption of power, the necessity of forming large quantities of slag, and incomplete magnetic concentration) are removed.

The practical application of the above-mentioned principle is obtained by De Vecchis in a very simple device consisting of a rotary kiln, where the ore is heated by gas or oil under suitable atmospheric conditions to about 1550° F., and cooled rapidly in water when coming out of the furnace, thus avoiding contact with the external atmosphere. The comparatively low temperature renders the process very economical in fuel and refractory consumption.

The "artificial magnetite" thus obtained is easily crushed in a ball mill to 60 to 80 mesh, and passed through an electro-separator. About 1.5% iron remains in the tailings. The concentrate is especially suitable, on account of its physical and chemical properties, for the production of a very pure sponge iron. Or, under favorable power costs, the oxide may be reduced in electric furnaces, giving a wide variety of high quality irons.

A typical analysis of a pig iron obtained from ordinary calcined pyrites (originally containing about 1.5% sulphur) is carbon 4.1 to 4.2%, silicon 0.15 to 0.20%, manganese traces, sulphur 0.01 to 0.03% and phosphorus traces.

Satisfactory results, both from the technical and economical point of view, have also been obtained by De Vecchis' method when working on the red slimes resulting from the treatment of bauxite by the Bayer process.

Federico Giolitti
Consulting Engineer
Bessemer Medallist

A Bottleneck in Steel Production?

New York City

To the Editor of Metal Progress:

I note your editorial comment on page 49 of the January issue under the heading "A Bottleneck in Steel Production?" In it you quote a statement by Chairman Olds of the U. S. Steel Corp. that "To date, the nation's defense effort has not been delayed by any shortage of steel and no such delays from that cause are anticipated by the industry", and immediately follow with sentences from *The Iron Age* telling of large back logs on the producers' order books and long forward deliveries quoted on new business.

This would lead one to infer, incorrectly, that *The Iron Age* had been disputing the statement made by Mr. Olds, to the effect that there has been no shortage of steel.

It seems to me that we first must agree on a definition of the word "shortage". If you place an order for steel with a mill today and expect to get it next week or the week after, as you could have done as recently as a year ago, you will undoubtedly be told that delivery cannot be promised short of eight or ten weeks or longer. We do not believe, however, that this can properly be called a shortage.

The fact remains that almost without exception every manufacturer using steel, including even those who would logically be classified as non-essential in this emergency, has been able to get all the steel he needed. He may be worried about his supplies some months hence. There has been no case that we have heard of where operations have been stopped, even temporarily, because of lack of steel. Some construction projects may be subject to delay, as, for example, a race-track which is to be built in Long Island, but this could hardly be classified as essential either to national defense or to national welfare.

In *The Iron Age* for December 5, page 103, we made the following statement:

"Recurrent talk of a 'steel shortage' finds no substantiation in the steel industry itself or among its customers. A careful check fails to reveal a single instance of importance in which either a defense plant or a non-defense plant has been affected in its operations by lack of steel. On the contrary, nearly all steel consumers are now comfortably situated as to inventories, and while deliveries are extended on nearly all products, complaints of steel companies' service are no more common than would occur under normal conditions."

We see no reason to change this statement. It is true that there are large back logs and long deliveries on wide plates, but don't overlook the fact that not all of this tonnage would take an A-1 rating if formal priorities should be invoked. Moreover, some of the continuous mills which now roll a variety of products, such as strip, black plate and skelp, could, if necessary, be turned entirely to plate production for such periods as might be necessary to overcome any shortage for essential work.

It is hard to prove, but I suspect that steel inventories in the hands of some steel consumers and distributors are perhaps larger than they ought to be. Apparently a similar situation may exist in Great Britain where the British Iron and Steel Control has been taking a census of steel stocks in the hands of users and distributors. If there is no excessive stocking of steel, the mills ought to be able to take care of all requirements — barring some temporary bottlenecks that may appear, such as now exist in electric furnace steel and wide plates, but for which remedies are being applied.

Tom Lippert of our editorial staff analyzed the situation in detail in *The Iron Age* for January 23.

C. E. Wright
Managing Editor
The Iron Age

Editor's Note — Other comment on this same important subject can be found on page 179 of Metal Progress for February and on page 299 of this issue. Since the latter was printed, the daily press has quoted President Roosevelt to the effect that the Office of Production Management has studied the situation and informs him that steel capacity (including announced and expected expansion of moderate relative size) will be sufficient for our defense effort and for civilian requirements even on the basis of an unexampled "national income".

This should settle the matter. However, whether it is called "shortage" or by some more euphonious name, the present situation of near-capacity operation and extended deliveries on new business is what might be called "unstable equilibrium". It can be quickly upset by unforeseen events. Witness the present squeeze in nickel. It reminds me of an editorial in *Metallurgical and Chemical Engineering* toward the middle of 1917, written by a man who ought to have known, saying that we could make all the nitrates and explosives we needed in existing factories, and within six months we were building powder plants all over the map!

A Pioneer, and a Man

Detroit, Mich.

To the Editor of Metal Progress:

I have enjoyed your review of the book about Sidney Gilchrist Thomas on page 215 of the February issue. As a former Britisher I was much interested in your notes about English amateurs and their contributions to metallurgy.

Lord Armstrong of Armstrong-Whitworth was another British amateur whose contributions to design and construction of heavy guns were noteworthy. Armstrong was a lawyer (of the variety known to the British as "solicitor") and was, I believe, without formal training in mechanical or scientific matters.

Armstrong is therefore worthy to be classed with Huntsman, Bessemer, Sorby and Thomas.

S. D. Heron
Research Laboratories
Ethyl Gasoline Corp.

The "Forging Cross" in Square Billets

Leoben, Steiermark, Germany

To the Editor of Metal Progress:

Some recent observations on the macrostructure of a hammer-forged square bar of steel, similar to the S.A.E. X1045 analysis, may draw comment from fellow members of in other countries. They have certain implications to the seemingly endless field of the influence of nuclei in metals, a field of study that has occupied much of my attention.

The etched cross-section of square-forged steels often reveals a cross-like pattern, which

(Continued on page 360)

Steel Cutting With Oxy-Gas Flame

Oklahoma City, Okla.

To the Editor of METAL PROGRESS:

In view of the dearth of accurate information concerning the economical possibilities of the oxy-gas flame for cutting steel, a summary of what we found in a five months' test may be of somewhat general interest.

This firm, Black, Sivalls & Bryson, manufactures large steel equipment for the oil industry, mostly welded products such as bubble towers, oil-gas separators, gas scrubbers, cylindrical tanks, and various kinds of oil treaters. We use a considerable amount of natural gas in our business, as for instance, for firing the $13\times18\times77$-ft. stress relieving furnace, for heating furnaces for bringing steel disks to temperature prior to pressing into dished heads, for forging furnaces and small forges. Since we also do a great amount of cutting, trimming and shaping of steel plate with the cutting torch, it was important for us to know whether the natural gas (very high in methane) could not be used direct from the mains rather than cylinder acetylene or acetylene from a generator.

It would be tedious to recount the details of our tests. The accompanying photograph shows the portable gaging equipment, wherewith we were able to study various operations in the shop. We tested, rather exhaustively, various makes of torches and tips, as well as several varieties of "bottled gas". Our work consists mainly in the cutting of new steel. This factor would be an important one in deciding what fuel gas would be most economical.

Portable Equipment Used by Black, Sivalls & Bryson, Inc., for Studying Labor, Gas and Oxygen Costs When Cutting Steel Plate in the Shop

The choice of equipment was found to be a deciding factor in our tests. For our use, one type of natural gas cutting torch resulted in an overall saving of 17% over any of the acetylene torches that were tested. This figure represents labor, oxygen, fuel gases, and allowance for depreciation of equipment.

We believe that the economics of oxygen cutting will change from time to time as new designs are brought out in the equipment for handling the various fuel gases.

HOWARD N. SIMMS
Metallurgist
Black, Sivalls & Bryson, Inc.

Heat Resisting Steels Without Nickel

Stalingrad, U.S.S.R.

To the Editor of METAL PROGRESS:

It is now known that the "self-supporting elements" for the production of heat resisting steels are basically silicon, chromium, and aluminum. These elements actively react with oxygen in the furnace atmosphere and give refractory oxides which cling fast to the surface. If these oxide films are broken, they heal themselves; they also resist thickening with time at temperature.

Messrs. WHITE, CLARK and MCCOLLAM, in *Transactions* for March 1939, state that silicon is the equivalent of seven times the chromium, and aluminum more than five times the chromium in the production of heat resisting surfaces. Studies in the U.S.S.R. also indicate positive action of copper with chromium and manganese in the sense of making a heat resisting steel. Accordingly, the Metallurgical Research Laboratory of the Stalingrad Tractor Plant has systematically investigated several nickel-free heat resisting alloys, using some of the standard chromium-nickel and high chromium steels and irons

Composition and Oxidation Rate of Chromium Steels Tested

No.	Chemical Composition									Gain* at 1835° F.		Gain* at 2015° F.	
	C	Mn	Si	Cr	Cu	Al	Mo	W	Ni	40 Hr.	80 Hr.	40 Hr.	80 Hr.
1	0.17	0.56	2.90	5.03		0.4	0.56			5.85	10.5	14.5	21.0
2	0.53	0.63	2.42	8.51		2.0	1.52			1.63	1.72	1.81	2.45
3	0.26	0.55	2.25	16.44	2.25					7.43	8.60	20.8	24.2
4	0.21	0.57	2.49	18.87	2.34	2.41				2.31	2.80	2.48	3.21
5	0.14	0.33	0.70	27.20						7.70	8.42	20.2	24.2
6	0.26	0.48	0.50	26.16						7.44	9.33	16.6	22.7
7	0.24	14.64	0.63	22.39						45.6	66.7	70.5	96.3
8	0.20	9.36	0.66	21.10			2.66			47.9	62.7	68.7	98.4
9	0.13	10.03	0.42	18.90				2.02				64.0	91.5
18-8	0.26	0.60	0.52	19.18					8.62	9.13	11.7	79.8	264.
18-25	0.34	0.36	2.70	17.58					24.75	2.51	2.90	10.9	14.6

*Gain in weight, figured to grams per square meter of exposed surface.

for bases of comparison. These studies include their strength at 70° F. and temperatures up to 1835° F., their heat resistance under lengthy heating up to 2015° F., and their microstructures. Some representative and interesting physical properties are given in the tables.

Heat resistance was determined on samples 8 mm. in diameter and 40 mm. long, heated in an open Globar furnace for various prolonged periods while resting in porcelain boats. Relative heat resistance was measured by determining the gain in weight and computing to grams per square meter.

From the first table it is seen that the following group of steels gained weight at 1835° F. at about the same rate as 18-8, namely No. 1, 5% chromium-silicon steel; No. 3, 16% chromium-copper steel; No. 5 and 6, high chromium.

On the other hand, Steel No. 2 (8% Cr plus silicon, aluminum and molybdenum) and No. 4 (18% Cr plus copper and aluminum) had the same heat resistance at 1835° F. as 18% Cr, 25% Ni, much used for heat resisting castings.

The data also show that all chromium-manganese steels (No. 7, 8 and 9) oxidized more rapidly.

Tests at 2015° F. show that plain 18-8 oxidizes too rapidly, therefore the 18-25 alloy was used as a standard of comparison. The large table indicates that the nickel-free steels No. 2 and 4 oxidize at only one quarter to one fifth the rate of 18-25; they are therefore not only good substitutes for such chromium-nickel alloys but are even more excellently heat resistant. The four other steels mentioned above, namely No. 1, 2, 5 and 6, also have heat resistance but little greater than 18% Cr, 25% Ni at 2015° F.

High temperature tensile results are given for the most interesting of these alloys, namely No. 2, 4 and 6. Long tension samples were mounted in a testing machine and surrounded with a tube furnace, brought to temperature slowly, soaked and tested at a slow rate of loading. The chromium-silicon steels, No. 2 and 4, have fairly satisfactory strength at 1650° F. The chromium-manganese steels (not shown in the second table) give ultimate strengths equal to 18-25 at temperatures up to 1835° F. Our tests generally indicated that the chromium-nickel steels preserve their strength quite well up to 1650° F., but in the range between 1650 and 1835° F. their strength decreases so that their superiority over the nickel-free steels becomes less as the temperature rises.

From these studies we have based the following conclusions:

Chromium-silicon steels with the addition of 2% aluminum and about the same amount of either molybdenum or copper (steels of the general type of No. 2 and No. 4 in the table)

Short Time, High Temperature Strength

Steel and Temperature	Yield Psi.	Ultimate Psi.	Elongation %	Reduction %
No. 2 (Cr-Si-Al-Mo)				
1650° F.	7,700	10,000	67.3	98.6
1835° F.		5,100	70.0	98.0
No. 4 (Cr-Si-Al-Cu)				
1650° F.	7,500	9,000	58.7	74.1
No. 6 (26% Cr)				
1650° F.	11,400	14,200	49.1	80.5
1835° F.	6,100	7,300	54.8	91.7
18-8				
1650° F.		21,400	44.7	80.8
1835° F.		6,800	52.5	86.2
18-25				
1650° F.	18,700	24,000	43.3	69.7
1835° F.		11,000	46.0	72.7

may be selected for services requiring extremely high heat resistance. These steels are also reasonably strong and very stable up to 1650° F., and at higher temperatures are inferior only to 18% Cr, 25% Ni steel. They are therefore very useful for many furnace fittings, plates, bars and other details working at high temperatures but under moderate load. (They can even carry good loads up to 1650° F.) For steels operating under heavy load at higher temperatures we use the high chromium and high chromium-manganese steels (No. 6 and 7).

We hope to report the results of extensive applications of these steels in due time.

M. P. Brown
Metallurgical Engineer
Chief of the Metal Research Laboratory
Stalingrad Tractor Plant

Martensitic Mule

Columbus, Ind.

To the Editor of Metal Progress:

The other day I found a black martensitic mule (male) at 3000 diameters in alloyed cast iron, evidently hiding under a giant fern. He seems to be far from home in some tropic clime, but the smudge pots must have been burning, to judge from the color of the leaves. Like other mules in these prairie states, he didn't care much where he was found, decided that the spot suited him, and emulating his stubborn brothers, just froze to it.

Harold H. Lurie
Chief Metallurgist
Research & Development Dept.
Cummins Engine Co.

Wrought Iron Viewed as an Iron-Phosphorus Alloy

Johannesburg, Transvaal

To the Editor of Metal Progress:

Although wrought iron has all but disappeared from the American industrial scene, over here it is still used and has been much discussed during the last decade. The spokesmen for wrought iron have always pointed to its alleged high resistance against fatigue. The supporters of high quality mild steel as a constructional material in preference to wrought iron have, on the other hand, dwelt chiefly upon the superior mechanical qualities of their steels as revealed in laboratory tests.

On this point there is hardly any disagreement. Tests made in diverse laboratories have all distinctly borne it out. The supporters of wrought iron have, however, claimed that such short-time laboratory tests — in particular fatigue tests — do not parallel the actual behavior in long-time service.

It is not yet possible to make a final comparison between the two materials, simply because good wrought iron was manufactured a very long time before the advent of high-class mild steels. It will therefore be left for future generations to ascertain the true comparative values.

Pending this verdict of history, the writer does not think it wise to disregard completely the evidence of our laboratory researches. Also, if there are any special merits in wrought iron, they must have distinct scientific reasons, and these should be ascertained and put forth.

Attention has often been drawn by the supporters of wrought iron to the high purity of the wrought iron base, but in point of fact the ferrite — quite apart from the slag inclusions in all samples that I have examined — always contains a considerable amount of phosphorus, very much more than the ferrite in any good mild steel. Since it has been recently found that phosphorus confers strength and some corrosion resistance to mild steel, one is inclined to ascribe the alleged corrosion resistance of wrought iron to this phosphorus content.

In the historic debate about the corrosion resistance of wrought iron and ingot iron recorded in the American technical literature before the last War, great stress was put on the advantage of pure iron. In our discussions over here concerning the corrosion resisting qualities

of wrought iron — whatever they may amount to — they have generally been ascribed consciously or subconsciously to the presence of the great multitude of slag inclusions. To remove the controversy from opinionated discussion demands an experimental study, in laboratory as well as in field tests.

Fundamentally, we can conceive the following systems:

A. High purity plain iron.

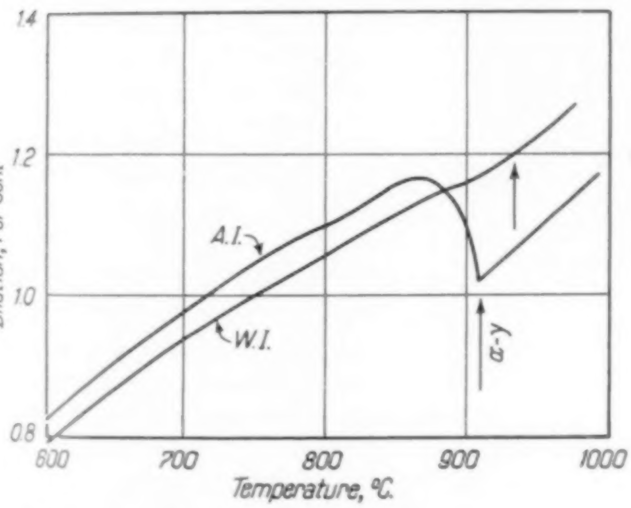
B. Plain pure iron, alloyed with phosphorus.

C. Plain pure iron, mixed with slag.

D. Plain pure iron, alloyed with phosphorus *and also* mixed with slag.

Systems A and D are well known to ferrous metallurgists in the form of ingot iron and wrought iron, respectively. System B has been studied a little in recent years. System C, however, has never been made and studied, as far as the writer knows. When it has been, it will be learned whether or not the slag plays a vital part in the durability or other properties of wrought iron.

My present view, that wrought iron is actually in its base an iron-phosphorus alloy, has never been given prominence. The writer was led to this view after he had made some dilatometric tests. The diagram accompanying this letter shows portions of two dilatometer curves, one for wrought iron marked W.I., and one for Armco iron marked A.I. The chief chemical difference between the iron base of these metals is the phosphorus content. That of the wrought iron may be put down as about 0.17%. That of the ingot iron is about 0.006%.



Dilatometer Curves Showing Pronounced $\alpha \rightarrow \gamma$ Change in Ingot Iron (A.I.) and Its Suppression in Wrought Iron Containing 0.17% Phosphorus

Both curves give the behavior of the samples during slow heating (2° C. per min. for W.I.; 4° C. for A.I.). Obviously there is a profound difference between these curves. The Armco iron shows a marked alpha-gamma transformation, complete at 909° C. The wrought iron curve is quite flat, with only an indication of the alpha-gamma transformation, complete only at 932° C. (Both temperatures are marked by arrows.)

A glance at the iron-phosphorus equilibrium diagram shows that this change in the transformation temperature is to be expected in this wrought iron. Also, the flatness of the curve is not an unexpected phenomenon, because the alpha-gamma transformation of iron-phosphorus alloys disappears completely at a comparatively small phosphorus content (0.7% according to a rough estimate). Therefore these dilatometric curves illustrate quite impressively the iron-phosphorus alloy in wrought iron.

The very existence of wrought iron and its long use in various states of refinement for all sorts of objects proves that iron and steel as such are not very sensitive to the presence of inclusions in many (not all) of their mechanical properties. However, an adverse if only small influence exists, and is felt in wrought iron. If wrought iron can claim any special merits (apart from the ease of welding which is an admitted and readily understood fact) it will be wise not to overlook its nature as an iron-phosphorus alloy in their explanation.

O. A. Tesche
Metallurgical Physicist
Steel Laboratory, State Mines

Errors to Be Corrected

Those who preserve files of Metal Progress will do well to correct the following errors in recent issues, mostly due to poor editorial work:

January 1941 issue: page 41. On the engraving the grain size numbers noted for both S.A.E. 6150 and T-1340 should read No. 7 at 1550° F. and No. 6 at 1700° F.

February 1941 issue: page 178 middle of left hand column, the sentence should read "Metals Reserve Co. has contracted with this source for 100,000 tons annually for three years." On page 194 the words "left" and "right" in the caption are obviously interchanged. On 222, first line, the quantity should read 1 lb. of water rather than 1 cu. ft.

PERSONALS

Ralph W. Dickson ⊕, laboratory foreman at Gary Works of Carnegie-Illinois Steel Corp. since 1937, has been made assistant to division superintendent of the central mills, quality control. **D. L. Simpson** ⊕, metallurgist, becomes chief observer, west mills, quality control.

Nominated — for president of the American Foundrymen's Association: **H. S. Simpson,** president, National Engineering Co., Chicago; for vice-president: **Duncan P. Forbes** ⊕, president and general manager, Gunite Foundries Corp., Rockford, Ill.; for directors: **L. H. Shannon,** vice-president and works manager, Stockham Pipe Fittings Co., Birmingham, Ala., **R. J. Allen** ⊕, metallurgist, Worthington Pump & Machinery Corp., Harrison, N. J., **James G. Coffman** ⊕, plant manager, Los Angeles Steel Casting Co., Los Angeles, Calif.; **Wm. J. Corbett,** vice-president and works manager, Atlas Steel Casting Co., Buffalo, N. Y.; **M. J. Gregory,** factory manager, Foundry Division, Caterpillar Tractor Co., Peoria, Ill.

Paul J. Seitz ⊕, formerly superintendent of American Metal Treating Co. of Cleveland, is now general manager for Commercial Steel Treating Co., also of Cleveland.

Promoted by Wolverine Tube Co., Detroit: **H. Y. Bassett** ⊕, to superintendent of tube manufacture; **J. S. Rodgers** ⊕, to head of the technical department, in charge of laboratories and mill control.

W. A. Cather, advertising manager of the Babcock & Wilcox Co., New York, has been made director of a program of market research and related activities adopted by the Seamless Steel Tube Institute, Pittsburgh.

James Williams ⊕, who was with the International Harvester Co. for the past seven years, is now with the Claud S. Gordon Co., as sales and service engineer with headquarters in Milwaukee.

Ashland Henderson ⊕, formerly metallurgist with the Frigidaire Division of General Motors Corp., has been named to the technical staff of Battelle Memorial Institute, Columbus, Ohio, as chemical engineer.

Welton J. Crook ⊕ is on indefinite leave of absence from Stanford University and is on duty in the Ordnance Department, as technical officer, Rock Island Arsenal.

C. T. Williamsen ⊕, Hyatt Bearings Division, General Motors Corp., Harrison, N. J., is now located in Canton, Ohio, expediting raw materials delivery for the purchasing dept.

PERSONALS

W. J. Long, manager of sales at the Worcester, Mass., office of Universal-Cyclops Steel Corp., has been transferred to the general offices in Bridgeville, as assistant general sales manager. **W. P. Knecht** has taken Mr. Long's place as manager of the Worcester branch.

Appointed as vice-presidents by Carpenter Steel Co.: **Frank R. Palmer**, assistant to the president, named vice-president in charge of sales; **Ernest J. Poole, Jr.,** general superintendent of the plant, named vice-president in charge of manufacture.

Arklay S. Richards is now occupying a newly erected office and factory in Newton Highlands, Mass., where he conducts an industrial instruments business.

Honored by the British Institute of Metals: **Paul Dyer Merica**, vice-president, International Nickel Co., Inc., awarded a platinum medal in recognition of distinguished services to non-ferrous metallurgy.

K. P. Rolston, formerly chief engineer, Screw Machine Specialty Co., Pittsburgh, has been made works manager in charge of mechanical production with the Hunter Manufacturing Corp., Bristol, Pa.

Tracy C. Jarrett, formerly assistant metallurgist with the American Optical Co., has been appointed chief metallurgist for Koppers Co., American Hammered Piston Ring Division, Baltimore, Md.

Serving as a part-time dollar-a-year technical expert for the United States: **Bradley Stoughton**, dean emeritus, College of Engineering, Lehigh University, Bethlehem, Pa., and national vice-president; in the capacity of head of the Section on Heat Treating Equipment in the Office of Production Management, Advisory Committee to the Council of National Defense, and also as a member of the Section on Metallurgical Problems of the National Defense Research Committee.

Harold B. Wylie, chairman of the Northwestern Pennsylvania Chapter, has resigned his post as research engineer at Talon, Inc., Meadville, Pa., to become works manager of the Casco Products Corp., Bridgeport, Conn.

C. S. Le Vake has been ordered to one year of active duty as a captain in the Army Reserve Corps, assigned to the First Field Artillery Observation Battalion, Fort Bragg, N. C.

P. C. L. Van Bueren has left Continental Industrial Engineers, Inc., Chicago, and joined Dempsey Industrial Furnace Co., Springfield, Mass., as assistant to the president.

PERSONALS

Samuel S. Post has been ordered to one year's extended active duty as a 2nd lieutenant at the Ordnance School, Aberdeen Proving Ground, Aberdeen, Md.

Gilbert R. Reed, Jr. is on active duty with the U. S. Army as 1st lieutenant, 106th Cavalry.

Robert C. Pultz has resigned from Jones and Laughlin Steel Corp. to accept a Civil Service appointment in the Navy Department as inspector of engineering materials at Huntington, W. Va.

Transferred by U. S. Steel Corp.: **Louis B. Haberman**, from the Research Laboratory at Kearny, N. J., to the metallurgical department of the Columbia Steel Co.'s Torrance Works, Torrance, Calif.

P. E. Maenner has organized a new engineering company under the name of Peninsular Engineering, Inc., Cleveland.

Roscoe R. Hershey has been made metallurgical sales engineer for graphitic toolsteels in the Cleveland branch office of the Steel and Tube Division of the Timken Roller Bearing Co.

G. J. Langenderfer has been transferred from the Michigan territory to the Chicago office of Surface Combustion Corp. as district industrial engineer in the standard industrial division.

W. H. Solger has been ordered to active duty with the First Armored Regiment, U. S. Army at Fort Knox, Ky.

R. M. Schaffert, formerly research physicist with Mergenthaler Linotype Co., is now with Battelle Memorial Institute as research engineer investigating printing plates.

Hugh E. Replogle, formerly with the Crucible Steel Co. of America, has joined the Universal-Cyclops Steel Corp. in a general toolsteel sales capacity.

Leslie L. Andrus, formerly sales manager, American Foundry Equipment Co., has been made vice-president in charge of sales.

Harry B. Pulsifer formerly metallurgist for American Steel & Wire Co., is now with American Metal Treating Co., Cleveland.

Transferred by Columbia Steel Co.: **Charles Lee Clayton**, from the San Francisco to the Los Angeles office.

Howard A. Smith, formerly of the Duraloy Co., is now associated with Universal-Cyclops Steel Corp. as research metallurgist.

Albert B. Castro is now with Westinghouse Electric & Mfg. Co. in the East Pittsburgh plant as assistant buyer for the Purchases and Traffic Department.

CREEP STRESS

(Continued from page 332)

or furnace cooling. Various grain sizes were then established by heating for 5 hr. at increasing temperatures above 1600° F.

Creep testing was done at 1022° F. A constant load was applied for the first 1000 hr., which gave a comparison of both the creep rate and the plastic elongation at the end of that period with the different grain sizes existing in the same steel. In each case the test was immediately continued for an additional 1000 to 2000 hr. as a step-down or decrement relaxation test to find the creep stress which would produce a constant creep rate of 1% per 100,000 hr.

The air-cooled steels have an acicular microstructure and the creep properties at 1022° F. are poorer in general than the results obtained with the furnace-cooled treatments applied to the same steels. Furnace-cooled samples have a well-developed mixture of sorbitic pearlite and ferrite grains; examination at 2000 diameters indicated a uniform carbide distribution in the pearlitic grains.

Assuming that the 1022° F. testing temperature is above the lowest temperature of recrystallization, but irrespective of the correctness of the assumption the tests show that:

1. Annealing improves the consistency of the test results and increases the observed creep strengths.

2. With an apparently constant microstructure in each of the annealed steels, the creep stress for a constant creep rate varies with the structural grain size that exists in the steel during the creep elongation.

3. The creep stress attains a maximum creep strength which corresponds with an optimum size of the structural grain.

4. A maximum value in the curve of creep strength versus grain diameter can apparently be produced by grain size in annealed steels alone.

5. The optimum grain size is different for each of the four differently alloyed annealed steels, the range in grain diameter not exceeding a one-to-two ratio.

We now turn our attention to a number of additional tests on 0.5% molybdenum steels. A statistical study of eight cast and wrought steels (carbon ranging from 0.10 to 0.50%) shows that the maximum creep strength and the corresponding optimum grain size both change with the temperature of the creep test. (Creep strength, as before, is expressed in psi. for a rate of 1% elongation per 100,000 hr.)

Having in view the three variables of maximum creep

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CREEP STRESS

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strength, optimum grain size, and creep temperature, under the approximately constant conditions of type of steel and microstructure, the following conclusions hold, at least for the important temperature range of 850 to 1000° F., at which much modern steam boiler and turbine equipment is operating:

1. At the lowest creep temperature the finest grained steel has the greatest creep strength.
2. At the highest creep temperature the coarsest grained steel has the greatest creep strength.
3. At intermediate creep temperatures an intermediate grain size has the greatest creep strength.
4. The maximum creep strength and the corresponding optimum grain size each vary as a continuous function of the creep temperature.

One can now formulate the relationships between creep strength, grain size and creep temperature for carbon-molybdenum steel (0.5% Mo). For No. 2 A.S.T.M. grain size the maximum strength is 12,000 psi. for 1% creep in 100,000 hr. at 1020° F. For No. 4 grain, it is 19,000 psi. at 930° F. For No. 6 it is 25,000 psi. at 850° F. A family of curves has also been constructed [shown in the original paper] that enables one to estimate the creep stress for any other grain diameter than the optimum. If the grain size is two numbers larger, the creep stress will be about 70% of the maximum. If the grain size is one number smaller the creep stress will be about 80% of the maximum.

A uniform grain size is important. Steel deoxidized with a strong grain growth inhibitor and finally heat treated in the coarsening temperature range often presents a duplex structure with areas of different grain size. The creep strength of the steel is weakened toward that of the weaker grain size.

Other steels, presumably heat treated just over the Ac_1 point, present grains with very irregular outlines, particularly between areas of ferrite and precipitated carbides. These steels have such low creep strength that acceptance for high-temperature turbine construction could not be considered. This method of predicting the creep strength, based upon the condition existing within the steel at room temperature, enables the consumer to judge the acceptance of a given requisition of steel and the designer to specify the steel with more confidence in the resulting product, and these principles have been used in appropriate specifications of the General Electric Co. since 1934.

LIGHT ALLOY

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surprisingly numerous. They include 60-ft. patrol boats and express cruisers, lifeboats, and well over a hundred small boats for all kinds of private, racing and Admiralty use. Where care has been taken to avoid corrosive anti-fouling paints, no trouble has been experienced from corrosion. One boat, "Barnacle Bill", has lain under conditions of deliberate gross neglect, with no adverse results. Many launches, torpedo boats, and speed boats have been constructed with light alloy frames and wood hulls. In these smaller craft the trend has already commenced toward the complete Navalium hull.

Various lake vessels of Navalium are in use in Switzerland, and a fair number of small craft in Germany. In most maritime countries the adoption of aluminum for internal ship work will be found to a greater or lesser extent. Warship applications are, of course, the most obvious and most extensive, and the experience here gained with particular alloys is producing a confidence which will ensure their future widespread use.

When built into a structure like a ship's hull, it is well known that aluminum deforms more than steel under a given unit load because of its lower modulus of elasticity. It is not so well understood that, with increased deflection in statically complicated structures, the determination of the bending moment distribution throughout the structure becomes more reliable. A further structural advantage is that economical sections can be readily extruded in aluminum, but not rolled in steel; likewise sections of variable thickness along the length of the material can be produced. Vibration problems are also of interest; the strain energy of the light alloy structure is very considerably greater than that of the steel structure, and thus the internal damping should be greater. Another feature is the comparative absence of vibrational noise in light alloy structures. Indent damage should also be very much less likely—an important feature in vessels having to dock frequently, and also for ice breakers.

In warships there is already a very extensive reduction in internal outfit weights brought about by light alloys. The savings in total weight so effected can be used to increase the machinery power, the armor, or the armament. The value of each ton saving depends upon how rapidly increase of power (and hence the required machinery and fuel weight for given radius of action) takes place with increased displacement. This

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LIGHT ALLOY

(Starts on page 320)

relative factor varies from about three in low speed warships to at least six in destroyers. Thus, for every ton saved by light alloys (or other cause), from three to six tons total weight can be saved.

The most important stage in the approach to the light alloy ship is the combination of steel lower hull and Navalium abovewater structure. Stability is at once improved. ROUGERON has shown that if the mid-ship section is one-third aluminum, the otherwise low stresses in the intermediate steel plating can be appreciably increased and the steel better utilized. This arrangement particularly referred to warships where the protective deck stresses were increased as a result of the combination due to the lowering of the neutral axis.

Extensive use of light alloys in ships is bound to decrease the cost of the metal. Present costs of aluminum in aircraft are by no means representative, on account of the preponderance of thin material and the losses in scrap. When the manufacture of Navalium is seriously undertaken, steel practice will obviously be followed and scrap returned to the mills. (This will be greatly assisted by the development of new scrap recovery and refining methods which have already passed the experimental stage, and appear to guarantee the production of super-quality ingots.) By that time the heavy initial costs of rapid expansion of the aluminum industry will have been written off.

The heavier units required for ship work, the greatly reduced overheads per ton and the use of entirely new methods will all combine to produce in the course of the next few years very substantial reductions in the price of Navalium. The halving of present ingot prices at least is the order of reduction reasonably to be expected, and it is of interest to view the matter from a steel cost standpoint. If Navalium were to cost three times the price of steel, ships would obviously then be built of Navalium, since the structural savings in a vessel of given duty would then be enormous. Even in a cargo ship it becomes attractive to use Navalium when its cost is five times that of steel. In naval vessels the case for Navalium is still more striking, as, of course, is to be expected from the already extensive use of light alloys in warship construction. If Navalium at nine times the price of steel (as at present) can produce more economical designs than steel even by the partial use of Navalium, the present price gap will soon be bridged without great difficulty.

A LABORATORY TEST FOR MACHINABILITY

By A. S. Kenneford

Abstract from Paper No. 849, British Institute of Metals, Fall Meeting 1939

EVER SINCE the classic work of TAYLOR and WHITE on high speed steel, near the turn of the century, it has been known that the cutting power of tool-steels (and its inverse problem, the machinability of metals) involves a very large number of variables. Workers on the problems have roughly ranged into two camps; one simplifies the matters as much as possible for quick laboratory determinations; the other simulates shop conditions — or actually tests in production runs — in order to submerge minor variations in a mass of results. [An example of the simple test for machinability is the time required for sawing through 1-in. bars with a good power hacksaw. J. D. ARMOUR described the extended manufacture of a screw machine part in METAL PROGRESS, January 1938, as an example of the "production" test.]

Among several attempts to put this property of machinability on a quickly measurable basis, four may be mentioned. REICHEL used, simultaneously, two cutting tools of different composition, and measured the e.m.f. (and hence the temperature) generated. This temperature was plotted against cutting speed, and the machinability of the metal taken as that cutting speed at which the tool would operate, without exceeding its safe working limit of temperature. NEAD, SIMS and HARDER used a more conventional method for steels, in the time taken to drill a hole of given depth and diameter, using constant rotation and feed. ROBINSON and NESBITT, in their experiments on the drilling of rifle barrels, concluded that metal with coarse banding was superior to that having a finer structure.

In the present work, a simple machine described in 1921 by OXFORD and AIREY in *Transactions* of the American Society of Mechanical Engineers was used. A single-bladed fly cutter, capable of machining a groove 0.125 in. wide, was mounted on a horizontal shaft so it rotates in a vertical plane. At the other end of this shaft is a weighted lever arm. The swinging of this weight from its vertical position furnishes the power necessary for driving the cutting edge into the work, and the power absorbed is measured by the swing of the pendulum past lower dead center (exactly as in an Izod impact

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MACHINABILITY

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test). The above described equipment is mounted on a tool post which can be lowered and advanced by micrometer screws into a metal test block, fixed with top surface horizontal. Three or four swings of the arm (cuts), alternating with successive lowerings of the tool, start a groove in the test block having a circular bottom; progressive advances of the tool post then give a type of cut similar to a milling cutter.

In general, ten cuts were made during the course of any one experiment, using a constant depth and feed per cut, the average energy absorbed per cut being taken, and metal removed per cut being calculated by collecting and weighing the chips. The energy absorbed in removing one cubic inch of metal has been used as a criterion of relative machinability.

The value so found varies widely over the range of materials tested, and those materials which have a high energy absorption are also those which are most difficult to machine in practice. Bad surface finish and short tool life are also generally associated with high energy absorption, as is also the formation of a chip which piles up on the edge of the cutting tool. It was impossible to correlate the work done in removing 1 cu.in. of metal with any of the usually determined properties such as tensile strength, compressive strength, work hardening capacity as determined by the Meyer *N* value, or hardness. It should be mentioned that the same tool has been used without lubricant for all the materials tested.

It was also found that as the feed increased, the energy required to remove 1 cu.in. of metal decreased appreciably. It would appear that, in general, the most efficient cutting is obtained by using the maximum possible feed and depth of cut compatible with good surface finish and long tool life.

Some experiments on "directional machinability" due to inclusions were interesting. This was, in fact, found, although to a rather minor degree. For instance, lead-free 70-30 brass required the same amount of work to remove metal in either parallel or transverse direction, whereas 60:40 brass with 2% lead required 1.79×10^{-4} ft-lb. in a parallel direction and 1.77×10^{-4} ft-lb. in a transverse direction, a decrease of only 1%. A free-cutting aluminum alloy extrusion, however, cut 6% easier transversely. The lower specific influence of the lead may be due to its presence in globules, whereas inclusions in aluminum are elongated strings.

"FORGING CROSS"

(Continued from page 335)

extends along the diagonals and is probably associated with the higher amount of slip or plastic movement that has occurred in these regions. This pattern, often called the "forging cross", can be influenced by heat treatment, as is shown by the following interesting observations on a bar of 0.45% plain carbon steel, rather low in manganese.

In the forged state the secondary microstructure (that is, the ferrite-pearlite mixture) of the whole bar, viewed in cross-section, is practically the same. Heatings to the range between 1450 and 1650° F., of which the latter is high above the Ac_3 point of the steel, cause the appearance of dark spots confined to the area of the forging cross, especially at and near the intersection of the two diagonals. These spots are readily visible with the bare eye; under the microscope they prove to be large islands of pearlite.

Heating now to 1825° F. and slowly cooling changes the structure markedly. After etching in a way to develop the traces of the pre-existing austenitic grain boundaries, it is noted that the regions outside the forging cross have experienced a general grain growth. However, the forging cross itself remains fine grained, except for the large pearlite islands, which obviously have been formed in the temperature range of 1450 to 1650° F. during the heating period.

Further heating up to 2000 and 2200° F. eliminates the fine-grained structure in the forging cross and the whole section now becomes coarse grained.

The causes of this remarkable behavior are not yet fully understood. It can be assumed that non-metallic nuclei are of main importance. The type of such nuclei can be altered by different methods of deoxidation, and a certain variation in the above phenomena has been found. The reason for the early preferred grain growth of pearlite areas in the region within the forging cross may be attributed to the change of the distribution of the non-metallic nuclei in the planes of main slip or plastic flow under the hammer.

ROLAND MITSCHE
Professor
Montanistische Hochschule

NOTES ABOUT CONTRIBUTORS

Graduated in 1922 from Baltimore Polytechnic Institute, **Paul S. Lane** continued his technical studies at Johns Hopkins University night classes. With Bartlett Hayward Co. in Baltimore he was chemist, metallurgist, and assistant foundry superintendent. After five years as chief metallurgist with American Hammered Piston Ring Co., he was placed in charge of research and engine test laboratories in 1936, when the latter firm became a division of Koppers Co. Since the first of 1940 he has been with Muskegon Piston Ring Co. as research engineer. He is a past chairman of the Baltimore Chapter.

R. S. Burns has done well with American Rolling Mill Co., and at the age of 33 is supervising metallurgist in the research laboratories. He has been with Armco since 1930 when he graduated from Ohio State University with an A.B., taking a metallurgical engineering degree in 1937. In 1933 he was co-winner of an American Iron & Steel Institute medal, and has collaborated in many papers published by the and the A.S.T.M. He now has charge of research and development work on sheets for drawing purposes.

Armed with a new Met. E. degree from Lehigh University, **R. M. Brick** started to work in the plush days of 1929. After a year under Jeffries and Archer at the Cleveland Division of the Aluminum Research Laboratories, he returned to school, Yale this time, and received a Ph.D. in the less auspicious year of 1933. Still at Yale, he does teaching, research and consulting work in the general field of physical metallurgy.

Possessed of a sharp brain, a practical turn of mind, and a sometimes caustic wit, **Gordon Williams** has been an invaluable member of the American Society for Metals. He has served the Cleveland Chapter as secretary-treasurer and chairman and as co-lecturer in an educational course; the National Office is indebted to him for a section of the Handbook, chairmanship of the 1939 Nominating Committee, and membership on the Metal Progress Editorial Advisory Board. He is currently conducting an educational course for the Tri-City Chapter (see page 323) with which he has been affiliated for the past two years as metallurgist in the laboratories of Deere & Co. (Cleveland Tractor Co., Harshaw Chemical Co. and Thompson Products, Inc. employed him in Cleveland from 1925 to 1939.)

As an undergraduate in chemical engineering **H. S. Jerabek** fell under the spell of metallography as taught by O. E. Harder at University of Minnesota, and has been on the staff in that department continuously since 1927 (now assistant professor of metallography). His only outside experience consists of five summers of research work at the U. S. Naval Research Laboratory, and two years as metallurgical consultant to the Chemical Engineering Research Division of the Tennessee Valley Authority. He is currently chairman of the North West Chapter.

Co-worker with Professor Jerabek at TVA was **William W. Wolf**, who has been in its Chemical Engineering Research Division for the past seven years. He has a B.S. in chemical engineering from University of Colorado (1931) and M.S. in physical chemistry (1933).

R. S. Burns

R. M. Brick

H. S. Jerabek

William W. Wolf

SHEET STEEL

(Cont. from p. 308) that are now obtained.

It will be noted from the last curves that the yield strength, tensile strength, and hardness of the cold-reduced annealed sheet in the fresh condition are lower and the percentage of elongation in 2 in. has been increased to the extent of approximately 2.5%. In addition, the metal has less tendency to buckle in the dies and to spring back when removed from the dies, due to the initially lower yield point which allows flow into the dies at lower unit stresses. The principal disadvantages with cold-reduced annealed sheets are their increased tendency to stretcher strain after short periods of aging, and their greater tendency to "draw ears" as compared to a normalized box annealed sheet.

As is usual where rapid progress has been made, the art in many cases has preceded the science, and were it not for the wholehearted cooperation of the body fabricators and stamping shops, it is quite doubtful whether the development of wide drawing sheets would be as far along as it is at the present time.

It is general sheet-mill practice to have mill representatives and metallurgists frequently visit the sheet-consuming industries so that any slight adjustments that are required in the sheet production methods can be made as the need arises. This enables the mill to understand the customers' requirements clearly and make changes in processing to meet specific requirements. In most cases the cooperation between the consumer and the mill has been so complete and satisfactory that it has been found unnecessary to write restrictive purchasing specifications covering the physical properties and chemistry of the sheets, the main requirement being that the sheets should be satisfactory for the job insofar as breakage, surface after drawing, and bad metal is concerned.

The sheet manufacturers will continue to cooperate with the users of sheets to meet new requirements and to improve the present products. There is much work still to be done in the steel plant and rolling mill in the matter of making better drawing sheets. Particularly are there opportunities for decreasing — or preferably, completely eliminating — the aging behavior which always develops if there is any abnormal delay in stamping sheets after they have been delivered. The very nature of the steel now used in the production of sheets for drawing purposes makes this a rather difficult undertaking, but the problem is not insurmountable.